Vol. 1.

RUDIMENTARY CHEMISTRY

FOR THE

USE OF BEGINNERS.

BY PROFESSOR FOWNES, F.R.S.

TO WHICH IS ADDED,

AN ESSAY ON THE APPLICATION OF CHEMISTRY TO AGRICULTURE.

Price 1*s.*

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BY

GEO. FOWNES, F.R.S.,

LATE PROFESSOR OF PRACTICAL CHEMISTRY IN UNIVERSITY COLLEGE, LONDON.

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JOHN WEALE,

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M.DCCC.LVII.

DURING a visit at Barbados, Professor FOWNES wrote and gave me the manuscript of this little book. I print it especially for the Barbados School of Practical Chemistry, but at the same time with the confident hope that it will be widely circulated beyond the limit of this Island.

WM. REID, Governor.

Barbados, January, 1848.

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PREFACE.

In all branches of human knowledge, depending upon experimental evidence, recourse must in teaching always be had to a double system of instruction; the interest and attention of the pupil must first be aroused and excited by experiments of a striking and yet suggestive nature, which may tempt him to thought and inquiry; to satisfy which, in part, a small elementary treatise on the subject may be put into his hands with advantage. If this be favourably received, and in some measure mastered, he will be in a condition to attend with great profit an extended course of well-illustrated lectures, and also in his intervals of leisure to peruse some systematic treatise on the subject, the hearing and reading being so combined, that the one shall throw light upon the other, and call into activity both judgment and memory. And this method of proceeding is especially applicable to Chemical Science, which rests entirely and exclusively on experimental demonstration, and to which the resources of Mathematics have not yet been applied.

In the hope of facilitating the acquisition by the pupil of a few general ideas respecting Chemical Science, the present rudimentary work has been drawn up. It is hoped that, from the little said, the desire to know more may be excited in his mind. But these and all such means will certainly fail unless an opportunity of seeing experiments themselves, or, best of all, of assisting at such experiments, be afforded. Chemistry can never be

learned by reading: it is in the lecture-room or the laboratory that the pupil makes, as it were, personal acquaintance with the different substances concerned; an acquaintance which is afterwards extended and rendered more perfect by the judicious perusal of books.

It is difficult to exaggerate the advantages which would result to individuals and to the community, if the elements of Natural Philosophy and Chemistry were regularly and systematically taught in schools, even those intended for the humbler classes of society. To say nothing of the positive gain which such knowledge would often prove in the common pursuits of life, being at every step so directly applicable to practice, the elevation and purity of mind which result from a taste for the study and observation of nature are surely most favourable to the advancement of the end and aim of all education—to qualify men for the faithful and true discharge of the duties and obligations of life, while awaiting with humility and hope the mysterious development of existence yet to come.

GEO. FOWNES.

Barbados, January 1st, 1848.

PREFACE

TO THE SECOND EDITION.

THE scientific writers who have been engaged in preparing the Rudimentary Treatises, of which the lamented Professor Fownes's work formed the first, having treated their respective subjects in greater detail than was done in the Rudimentary Chemistry, and the great success of the Series appearing to sanction this extension, the Publisher has found it necessary to enlarge this treatise. Professor Fownes himself shortly before his death had revised the work, and made a few additions; but, these not being sufficient, the Editor has added an Appendix, founded upon a suggestion contained in the eloquent passage at the conclusion of the work:—"We are already permitted to see more or less perfectly many links of this wonderful chain of actions; we see the carbonic acid, water, and ammonia, bone earth and the alkalis, restored to the air and the earth by the breathing of the animal during life, and by the decay of its body after death, employed in forwarding the growth and maintenance of another and different race of organic beings, the vegetables, namely, of the field and forest, which under the influence of the sun's light decompose this carbonic acid and ammonia, restore a great part of the oxygen to the atmosphere, and employ the remaining elements in the formation of those complicated products of or-

ganic life which art yet in vain endeavours to imitate. Life and death succeed and are dependent upon each other; the individual perishes, but the race remains."

In this Edition the *Rudimentary Chemistry*, as revised and slightly enlarged by Professor Fownes, has been carefully re-produced: for the new matter contained in the Appendix the Editor is responsible.

London, April, 1849.

In consequence of the unprecedented sale of large impressions of the several Editions of this useful Book, a new Edition is again presented to the public.

November, 9, 1852. J. W.

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RUDIMENTARY CHEMISTRY.

THE Science of Chemistry has for its object the study of the nature and properties of the different substances of which the earth, the waters, the air, and their inhabitants, (namely, plants and animals,) are composed. In a word, it embraces the study of everything under heaven accessible to man. In its highest branches it aims at discovering the laws or rules which regulate the formation of chemical compounds generally, and in its useful applications it has been already exceedingly serviceable in directing and improving the various arts of common life, as agriculture, the working of metals, dyeing, and many other pursuits. It serves also to guide the medical man in the preparation of his remedies, and also occasionally in distinguishing between diseases which are in other respects much alike. There is, indeed, scarcely a situation in life in which a knowledge of chemistry may not prove directly useful. Lastly, it is a science, the study of which, from its simplest beginnings to its highest attempts, is rendered delightful by the constant succession of new and interesting things brought before the eye and the mind.

Almost all the substances just spoken of as the objects of chemical study, namely, the various rocks, clays, sands, and soils which compose the solid earth; the water of seas and rivers; the materials of plants and animals, are of a compound nature, that is, made up of two or more other substances united or combined to-

gether in a manner so close and intimate as not to be generally separable by any common means; and the compound so produced is almost always different in properties and appearance from the substances of which it is really composed. These latter may themselves be of a compound nature, and each formed in like manner by the union of two or more other substances very strongly joined together, but still capable of separation by proper chemical means. Such an act of separation is called by the name of *chemical decomposition*, and the original compound substance is in such a case said to be chemically decomposed into its *components* or *constituents*. Some of the means employed to bring about chemical decomposition will be described in their place.

As an example:—a piece of limestone, coral-rock, or chalk, heated red-hot for half an hour, loses nearly half its weight, and becomes quicklime. The loss is caused by the separation from the limestone of another substance (called carbonic acid) which is carried off by the vapours of the fire, but which could be easily caught and collected by proper means. The limestone is therefore decomposed by the action of heat into its components, lime and carbonic acid, which by their union formed the limestone, or, as it is called in chemical speech, carbonate of lime.

Both the carbonic acid, however, and the lime, are themselves of a compound nature; the first may be decomposed into two other substances, carbon and oxygen, and the second into a metallic matter, calcium and oxygen. Mere heat, indeed, will not produce this effect, which can only be brought about by very powerful means of decomposition.

In this manner a limit or boundary is sooner or later reached, and substances obtained which completely defy the efforts of the chemist to decompose them further;

the carbon, oxygen, and calcium of the limestone arrived at by two successive steps of decomposition are found to resist all further attempts at decomposition;—such substances are called *simple* or *elementary*, or sometimes, *chemical elements*.

The number of these elementary substances known to exist alters with the progress of chemical science; substances which at one period resisted decomposition gave way when new and more powerful means for that purpose were applied; besides which, minerals and waters containing new elements are met with from time to time. At present they amount to sixty-one. Very many of them, however, are exceedingly rare, the compounds containing them being found in very small quantities.

Elementary substances are always divided by chemists into two classes, namely, *metals* and *non-metallic substances*. The well-known and abundant metals, gold, silver, copper, iron, tin, and lead, together with a great number of rarer and less familiar substances, will stand in the first class. The components of the atmosphere, oxygen and nitrogen, hydrogen, sulphur, phosphorus, and several others, belong to the second class. Several of the elements, however, possess properties which render it difficult to decide in which class to place them. The list below embraces the whole:—

NON-METALLIC ELEMENTS.

Oxygen.	Chlorine.
Hydrogen.	Bromine.
Nitrogen.	Iodine.
Carbon.	Fluorine.
Sulphur.	Silicon.
Selenium.	Boron.
Phosphorus.	

METALS.

Group I.	Potassium.
	Sodium.
	Lithium.
Group II.	Barium.
	Strontium.
	Calcium.
	Magnesium.
Group III.	Aluminum.
	Glucinum.
	Yttrium.
	Erbium.
	Terbium.
	Zirconium.
	Thorinum.
	Cerium.
	Lantanum.
Group IV.	Didymium.
	Manganese.
	Iron.
	Chromium.
	Nickel.
	Cobalt.
	Copper.
	Zinc.
	Cadmium.
	Bismuth.
	Lead.
Group V.	Uranium.
	Vanadium.
	Tungsten.
	Molybdenum.
	Columbium.
	Niobium.
	Pelopium.
	Titanium.
	Tin.
	Antimony.
Group VI.	Osmium.
	Gold.
	Mercury or Quicksilver.
	Silver.
	Platinum.
	Palladium.
	Iridium.
	Ruthenium.
Group VII.	Rhodium.

ELEMENTS OF INTERMEDIATE PROPERTIES.

Arsenic. Tellurium.

Nearly one-half of these are substances too rare and unimportant to require the attention of the young student in chemistry.

It is very important to understand what in science is called *physical state* or *condition* of a substance, simple

or compound, as contrasted with its chemical nature. There are three such states, the *solid*, *fluid* or *liquid*, and *gaseous*, which one and the same substance may assume, passing from one to the other, backwards and forwards, without the slightest change of chemical nature. For example, water, as commonly met with, is liquid, but when cooled sufficiently it takes the solid form, and becomes ice; and, on the other hand, when sufficiently heated, boils and becomes steam or vapour, which is the gaseous condition of water. By cooling this vapour, it again becomes liquid, and, by still further cooling, it freezes to ice, and all this without the least chemical change or decomposition of any kind. The metal zinc melts easily when heated to a moderate extent, and, when still further heated, vaporizes, or becomes converted into vapour, which, by cooling again, becomes liquid, and lastly, solid. In fact, very many substances, simple and compound, behave in the same manner, and have the power of existing in all three states, and a still greater number in two of them, the solid and the liquid, or the liquid and the gaseous.

Although a gas or vapour (which is the same thing in reality) is very frequently invisible to the eye, it is as much substance or matter as a solid or a fluid; it fills vessels, and possesses weight, and can be handled and experimented with, by proper means, with as much ease and certainty as a solid or a liquid. Some gases, however, are coloured yellow, violet, or red, and then they become of course evident to the eye.

The physical state of a substance is, in fact, dependent upon its relations to heat;—a subject which must now be considered.

HEAT.

The most remarkable and general effect of heat is to

cause *expansion*, or enlargement. A piece of iron or brass, made hot, will be found to be larger in all its dimensions than when cold; it will be longer, broader, and thicker, although without any alteration of weight. If it be artificially cooled by ice, on the other hand, it will become smaller in all its dimensions than before.

A pint of cold water or spirit of wine, made hot, measures while hot, more than a pint, and, when cooled by ice, less than a pint.

A bladder two-thirds filled with air, and the neck securely tied, becomes completely full when held for some time before a fire, so that the air may be well warmed, and shrinks again to its former bulk on cooling. Many other examples might be given of the effects of heat in causing expansion in solids, liquids, and gases; it is an effect which is general*.

The thermometer is constructed on this principle:—a very narrow glass tube is taken, with a bulb or ball blown at one end, and enough quicksilver introduced to fill the bulb and part of the stem, after which the open end of the latter is closed, by melting the glass together. When this instrument is heated, in obedience to the general rule, or law, the quicksilver expanding, or enlarging in bulk, rises in the stem, and, when cooled, sinks, from contraction or shrinking of the liquid metal, so that the instrument becomes to a certain extent a measure of heat; and by making marks on the stem, or by fastening it to a scale of wood or ivory, upon which marks can be made, its usefulness for this purpose is

* A most remarkable exception to the regular law of expansion by heat is found in the case of water, which acquires its greatest density between the temperatures of 39° and 40° Fahrenheit. From this point, both heat and cold cause *expansion*. This exception is attended with exceedingly important consequences in the economy of Nature. This subject is examined at some length in Mr. Tomlinson's "Introduction to the Study of Natural Philosophy."

increased. Such marks or divisions are called *degrees of heat*, or *degrees of temperature*, the heat or cold, or *temperature*, of a liquid into which the thermometer is plunged, or of the air which surrounds it, being then measured or judged of by the mark or degree opposite to which the top of the column of quicksilver in the tube stands.

It is of course necessary in practice to adopt some plan for so dividing thermometer-scales as to render them alike, and make the degrees of one agree exactly with those of all the rest, and this is done by the help of two *fixed points of temperature*, namely, the temperature of melting ice, and the temperature of boiling water. The former never varies, and the latter only to a small extent, and under conditions which are well understood. The thermometer being plunged first into the one and then into the other, and the height of the quicksilver in each case carefully marked, the space between can be divided by a pair of compasses into degrees, which may be extended in like manner below the temperature of melting ice, and above that of boiling water. This temperature of melting ice is often called the freezing point, water beginning to freeze, and ice to melt, at the same temperature.

Thus it will be seen that in the division, or *graduation*, of a thermometer-scale, the only fixed and invariable points are the freezing and the boiling points of water, which are always the same on all thermometers; the space between may be divided into as many degrees as the maker pleases, and the degrees made large and few, or small and many. In English thermometers this space or interval is divided into 180 degrees; in French thermometers into 100 degrees. On the latter scale the degrees begin with nought at the freezing-point, and run up to 100 degrees at the boiling-point; on the

English scale, called the *Fahrenheit* scale, after the name of the inventor, besides the degrees being smaller, the nought or *zero* is placed 32 degrees below the freezing-point of water, so that the boiling-point of water on this scale is 212 degrees, instead of 180. It is necessary to understand that to express the word degree, a sign or symbol is always made use of, which is a little °, or circle, placed on the right of the number, as in the following examples:—

Temperatures according to the English Thermometer.

Commencement of scale	0°
Freezing-point of water . . .	32°
Temperature of the blood . . .	98°
Boiling-point of water	212°
&c. &c. &c.	

Below 0° the numbers run in the opposite direction, being distinguished from the ordinary degrees by the negative sign (—). Thus, the temperature at which quicksilver freezes is expressed by — 40° F., or 40 degrees below the zero of Fahrenheit's scale.

Spirit of wine is sometimes used for filling thermometers, and even air, for particular purposes, but those containing quicksilver are most generally useful.

Another curious property of heat is its power of penetrating different substances, or, as it were, travelling through them, and passing from one to another when these touch. This is called the *conduction of heat*, and substances are said to be good or bad *conductors* of heat as they permit this passage to take place with ease or difficulty. If a piece of iron rod, the size of the finger, and six inches long, have one of its ends thrust into the fire, the other end becomes in a very few minutes too hot to be touched, but a glass rod of the same dimensions might have half its length melted

away before the heat penetrated to the other end so as to be felt. Hence, the iron is said to be a good conductor of heat, compared with the glass, which is a bad one. The metals generally are good conductors; stone, earthenware, glass, wood, charcoal, water, and air, very bad ones. Water and other liquids, however, become very quickly heated when the fire is applied below them; this is not the effect of easy conduction, however, but arises from another cause, which will be explained further on.

Something has been already said of the effects of heat in changing the physical state of substances; a few words on this subject may now be added. The change from solid to liquid, and from liquid to gas or vapour, in other words, the melting and boiling points of different substances, simple and compound, take place according to fixed and invariable laws. The melting-point of the same substances is always the same by the thermometer; the boiling-point, too, is always the same, when not disturbed by causes, which, as already mentioned, are understood and can be reckoned upon. The case of water has just furnished an excellent example of this perfect regularity, which is quite universal, so that in practice the melting and boiling points, as observed by the help of the thermometer, are often of the greatest use in distinguishing between substances which much resemble each other; each having its own particular melting or boiling point. A few of these are placed below by way of example:—

Melting-Points.

Ice melts at the temperature of .	32°
Wax	140°
Sulphur	238°
Tin	442°
Lead	612°

Boiling-Points.

Ether boils at the temperature of .	96°
Spirit of Wine	173°
Water	212°
Oil of Turpentine	314°
Sulphuric Acid	620°

The process called *distillation* consists in converting by heat a liquid into vapour, and then condensing that vapour, or causing it to return to the liquid state, by applying cold; it is used for separating substances from each other which differ in volatility; that is, require different degrees of heat to convert them into vapour. Thus, in making rum, a liquid containing sugar among other things, is exposed to the air and allowed to ferment, as it is called, by which means the sugar is destroyed, and in part converted into spirit, which is then separated from the water with which it is mixed by distillation. The spirit being more volatile than the water, boils first and soon begins to distil over, at first very strong, but afterwards weaker and weaker, until all has been separated, and nothing but water drops from the condenser. In like manner, salt water may be rendered fresh and pure by distillation, the water alone being vaporized, and the salt left behind in the still, salt not being volatile at the temperature of boiling water, or indeed at a much higher temperature. The instruments or *apparatus* used for distillation differ very much in make and materials, being suited to the particular purpose to which they are to be applied, but the principle is the same in all; there must be a boiler, where the liquid is converted into vapour by heat, and a condenser, where the vapour returns to the liquid state. The latter is very often nothing more than a long twisted pipe, plunged into a tub of cold water. For

acids and other corrosive liquids employed in chemistry, vessels of glass must be used.

The conversion of a liquid into vapour may take place without actual boiling, and at temperatures far below the boiling-point of the liquid. A little water or spirit of wine put into a saucer or plate, and exposed to the air, soon dries up, or *evaporates*, in warm weather, especially if the wind blow over it. This evaporation takes place only from the surface, and thus differs from evaporation or vaporization (for the words have the same meaning) at a boiling-heat, by the absence of bubbles of vapour which in that case form against the hot bottom and sides of the vessel, rise through the liquid, and break at the surface. It is for this reason that vapour of water is always present in the air in greater or less quantity, in a perfectly transparent and invisible and truly gaseous condition, and it is by the condensation or liquefaction of some of this vapour by the cold of the upper regions of the air that clouds are formed. These latter are said to consist at first of exceedingly small bubbles or bladders of liquid water, which afterwards break and run together into drops; the drops by the union of many rapidly increase in size, and at last descend to the earth as rain. This rain consists of water distilled by a natural process, the heat of the sun causing rapid and abundant evaporation from the surface of the sea, moist land, and the leaves of trees and plants, the vapour being brought back to the liquid form in the manner stated. The earth is perpetually refreshed, and its fertility renewed, by showers of pure fresh water, derived by distillation from the salt sea. The water sinks into the ground, carrying with it the materials (chiefly obtained from the air) required for the food of plants. That which is not sucked up and consumed by the latter, creeps along underground

in the sandy and looser portions, until, stopped by a bed of clay, or other material, which it cannot penetrate, it breaks forth as a spring. A little brook or rivulet arises, which, rippling down the valley, and being joined on its way by one little stream after another, grows at last into a river, and pours its waters into the ocean.

It must be clearly understood, that not every solid substance is capable of being melted and vaporized, every liquid solidified, or every vapour condensed; many compounds will not bear the application of heat without chemical decomposition; and again, our means of producing heat and cold, especially the latter, are not always sufficiently powerful to bring about the change that may be desired. Thus, there are certain substances only known to us in the gaseous condition, as oxygen, nitrogen, and hydrogen, the materials of the air and of water, which for want of sufficient command of cold have never been reduced to the solid or even the fluid state, and which for this reason are sometimes called *permanent gases.* In all other respects, however, these exactly resemble condensible vapours; and in fact many substances of this class, which a few years ago would have been so described, have lately, by the discovery of a more powerful means of producing cold, been liquefied, and even rendered solid. On the other hand, several of the metals can only just be melted by the most violent heat producible by art, and these of course cannot be volatilized by any means at present known, since volatilization in almost every case requires a much higher temperature than melting or liquefaction.

The general lesson to be learned from these facts is this:—that substances of all descriptions differ so far among themselves in their relations to heat, that is, in the manner in which they are affected by the same degree of heat, that while some at the common temperature

of the air are solid, others are liquid or even gaseous from melting or volatilizing at a comparatively low degree of heat.

LATENT HEAT; CAPACITY FOR HEAT.

When equal weights of hot and cold water are mixed together, the temperature of the mixture is found midway between that of the one and the other; but where equal weights of hot water and powdered ice are mixed, the temperature of the mixture is found to be *very far lower* than that of the middle point, or mean, of the two temperatures. If, for example, the ice be at 32° and the water at 174°, the mixture will only have the temperature of 32°. It will be all water, however, and the ice will have entirely melted. Now this apparent loss of heat, to the extent of 142°, is connected with the change in question, namely, the conversion of ice into water. The heat is said to have become *latent*, from a Latin word meaning to conceal.

When water freezes, the opposite effect takes place, and heat to the same amount is given out or developed. By particular management, water may be cooled far below its freezing-point without the production of any ice. By putting pure water into a perfectly clean glass jar in a very quiet place, in extremely cold weather, its temperature may be brought down ten degrees or more below the freezing-point, without any ice appearing. In this state, if it be shaken or stirred, a small portion instantly freezes, and the temperature of the whole, water and ice, rises to 32°. This rise is caused by the heat disengaged from the comparatively small quantity of water which becomes ice.

Thus, it is evident, that when in the winter water approaches the temperature of the freezing-point, instead of a little additional cold converting it at once into ice,

very severe and long-continued frost is required for that purpose, since all the latent heat given up by each portion of water which successively freezes must be carried away and disposed of before any more ice can be formed. On the other hand, the great masses of snow and ice which accumulate during the winter in many mountainous countries, rendering latent in their liquefaction such a large amount of heat, melt very slowly even under the summer sun, and furnish moderate and regular streams, which become the feeders of the great rivers of the earth, instead of sudden and overwhelming floods, which would follow rapid fusion.

That which has been stated of water is perfectly true of all other substances;—the passage from the solid to the liquid state is always attended with apparent loss of heat, and the change in the opposite direction with the disengagement of heat, although to an extent differing very much with different substances.

In vaporization heat is rendered latent, often to a wonderful extent, and again set free, to the same amount, on condensation. Steam passed into cold water exhibits most remarkable heating powers; but, on the other hand, to convert water into steam a very large supply of heat is wanted. All these effects are beautifully seen in the process of distillation, and in the action of the condensing steam-engine.

The surface-evaporation of liquids, before described, is always attended by cold, from the heat carried away in the latent state by the vapour. The degree of cold produced depends upon the rapidity of the evaporation. The wetted hand feels cold, and the wetted thermometer-bulb causes a fall of temperature to be shown by the instrument, although the water into which it was dipped might have been no colder than the air. By trying these experiments with a more volatile liquid than water,

such as ether, the effects are still more marked. On this principle, by particular management, water may be frozen by the rapid evaporation of a portion.

Different substances are not equally affected by the same amount of heat; in other words, very different quantities of heat are required to raise equal weights of different bodies through the same number of degrees of temperature. No change of state is here supposed to occur, the substance, whether solid or fluid, remaining solid or fluid during the experiment. If water, oil, and quicksilver be compared in this manner, it will be found that to raise equal weights of these liquids a certain number of degrees, less real heat will be required by the oil than by the water, and very much less by the quicksilver than by the oil. For this reason, if equal weights of hot water and cold oil be shaken together, and the temperature examined by a thermometer, it will be found *higher* than the mean temperature of the two; and if the conditions of the experiment be reversed, and cold water and hot oil taken, it will be found *lower* than that of the mean. This fact is expressed by saying that these bodies have different capacities for heat, the water having the greatest capacity for heat, the oil less, and the quicksilver least of the three. Every substance has its own particular capacity for heat, but of all those yet examined, water has by far the highest.

This is a very curious and important but difficult subject, and cannot be fully discussed in a little work like the present.

SPECIFIC GRAVITY, OR WEIGHT.

The words "light" and "heavy" in common speech are almost always used in a particular sense, something more being meant than the words really express; they are connected with the idea of *bulk* or *volume*. A piece

of lead is said to be heavy, and a piece of pine-wood light, because if pieces of *equal size* be taken and compared, the weight of the former will very greatly exceed that of the latter. To point out and express in an exact manner this common and familiar connection between weight and bulk, the term *specific weight* or *specific gravity* is used.

Thus, a bottle which holds 1000 grains of water will hold 1080 grains of good sugar-cane juice, 1340 grains of molasses, 1840 grains of sulphuric acid, 13,500 grains of quicksilver, and only 830 grains of spirit of wine. These numbers give a comparison of weights under the same bulk; in other words, they represent the specific weights of the bodies named, the specific weight of water being represented by 1000. In the same manner the weights of like bulks of solids and of gases can be compared, either among themselves or with liquids.

To form a table of the specific weights of various substances, therefore, it is necessary to choose one of these as a starting-point, or standard of comparison, and to give to it a number representing its particular specific weight, and then to try by experiment what proportion this weight bears to the weights of an equal bulk of other bodies to be examined, or how many times it is contained in the latter, the numbers expressing which will be the specific weights of the substances. In practice, pure water is always taken as the standard of comparison for solids and liquids, and pure atmospheric air for gases, and the numbers 1 or 1000 as their specific weights; this is done for convenience only, as any other substances and any other numbers might have been chosen. In the following table the specific weights or specific gravities of a few substances are put down by way of example. In the first column of numbers, water and air are put down at 1000, and in the

second column are made equal to 1, decimals being employed; the latter method is that generally followed.

Solids and Liquids.	Specific Weights,	Specific Gravities.
Water—	1000	1·
Platinum	21500	21·500
Gold	19500	19·500
Lead	11450	11·450
Silver	10500	10·500
Copper	8960	8·960
Iron	7800	7·800
Diamond	3500	3·500
Rock-crystal	2600	2·600
Window-glass	2520	2·520
Wax	964	·964
Quicksilver	13500	13·500
Sulphuric Acid	1840	1·840
Water	1000	1·000
Oil of Turpentine	865	·865
Spirit of Wine, strong	830	·830
Ether	720	·720
GASES.		
Atmospheric Air	1000	1·000
Oxygen	1106	1·106
Hydrogen	69	·069
Nitrogen	972	·972
Carbonic Acid	1524	1·524
Chloride	2470	2·470

Some of the experimental methods by which the specific weights of bodies are determined may be here shortly noticed.

With liquids, nothing is easier, since they have only to be weighed in the same bottle or flask filled to the same mark, and the weight compared with that of an

equal bulk of distilled water. The temperature must, however, be carefully attended to, and, indeed, should not vary from a standard temperature chosen, since different liquids expand by heat very unequally. In practice it is usual to employ a bottle holding exactly 1000 grains of water at 60°, chiefly with a view of avoiding the little calculation which an odd number would render necessary.

With solid substances in mass the question appears more difficult, but is answered with almost equal ease by the aid of a discovery made in ancient times by a philosopher of Syracuse, in Sicily, named Archimedes. A solid body plunged into a liquid appears to lose a portion of its weight, or to be in part supported by the liquid; a stone too heavy to be lifted by the hand, may be moved about under water with perfect ease. Its weight appears reduced, inasmuch as it is really in part borne by the water. Now there is no difficulty in proving, both by experiment and by reasoning, that in all such cases the apparent loss of weight is exactly equal to the weight of the liquid displaced by the solid body, namely, that of its own bulk. To determine the specific weight of a mass of solid matter, therefore, we have only to weigh it as usual in the air, and then to attach it to a fine thread and weigh it immersed in pure water at 60°. It weighs much less, the difference being the *weight of an equal bulk of water*, which is all we require to know. Hence the rule given in books:—"Divide the weight in air by the *loss of weight* in water, and the quotient will be the specific gravity."

The same principle guides all these operations, although the method has often to be altered to meet particular cases, as when the substance to be examined is in fragments or powder, or lighter than water, or soluble in that liquid.

Floating instruments, called hydrometers, are often used for finding the specific gravities of liquids, instead of the bottle and balance. In a dense or heavy liquid the hydrometer floats high out, and in a lighter one sinks deeper, since to float at rest a body requires to displace its own weight of the liquid in which it lies. By properly graduating the stem of the instrument, therefore, it may be made to give the information wished for within certain limits.

The specific gravity of gases is found on the same principle as that of liquids, namely, by taking a glass globe or flask, weighing it when full of dry air, again when emptied of air, as far as may be done, and a third time when filled with gas. The weights of equal bulks of air and gas are thus ascertained. The experiment requires, however, in practice the observance of many precautions and great care, besides apparatus of a very perfect and costly kind, if accuracy be desired.

The manner in which liquids, which are extremely bad conductors of heat, become rapidly hot when the fire is applied to the bottom of the vessel containing them, will now be easily understood. The part next the bottom getting hot, expands; its specific weight is therefore diminished; it rises to the top, while its place is supplied by another portion of colder, and consequently heavier, liquid, which in its turn becomes heated and expanded. In this manner the heat of the fire is *carried*, not conducted, to all parts of the liquid, movements or currents being set up, ascending in the middle and descending at the sides, and which are easily rendered visible when the experiment is made with a glass flask of water over a lamp by adding a little saw-dust.

Gases, which are still worse conductors than water, become heated in the same manner. The air itself is

so heated by lying upon the earth heated by the rays of the sun, which pass through air without in the least warming it. By this unequal heating, currents of air are formed, and this is, in fact, the origin of winds.

DESCRIPTION OF SOME OF THE MOST IMPORTANT ELEMENTARY SUBSTANCES.

Oxygen.—Of all the elementary substances this is the most abundant in nature, the most important to living beings, and that with which the study of the elements may be best begun.

Oxygen is only known to us in the form of gas; no degree of cold yet applied has rendered it liquid or solid. It is procured with great ease by heating the salt called chlorate of potash, and by many other means, which are taught in books of Chemistry. It is colourless and invisible; a little heavier than common air, bulk for bulk; and is not dissolved or *absorbed* to any notable extent by water. Its most striking property is to support *combustion*, or burning. A lighted taper plunged into a bottle of oxygen gas burns with greatly-increased brightness, and if before introduction the flame be blown out, so that the snuff remains red-hot, it is instantly rekindled. Charcoal, tinder, sulphur, and phosphorus, burn in oxygen much more rapidly and violently than in air; the flame of phosphorus is so splendid that the eye cannot look upon it. Thin iron wire, and steel watch springs, heated in this gas burn brilliantly, throwing off showers of sparks, and dropping in melted beads so intensely hot that when they fall into water they remain visibly red for some seconds. These are the effects observed when combustible substances are burned in pure oxygen.

The power which common air possesses of supporting combustion is entirely dependent on the oxygen it con-

tains, air being a mixture of this gas with another, to be described shortly, which is quite inactive, taking no part whatever in the matter, and merely serving, so far as we can judge, to moderate and diminish the violence with which burning would otherwise go on. The effect is the same with oxygen and with common air in the end, the only difference being, in the first case, increased energy, heat, and light.

Common air is necessary to the maintenance of animal and vegetable life, as well as of fire, and this is also due to the oxygen it contains, without which all living creatures would perish from the earth and the waters. An animal, however, cannot breathe pure oxygen many minutes without injury or death; it requires to be weakened or *diluted* in the manner beforementioned to render it fit for the support of life. Oxygen enjoys a wonderful power of entering into combination with other substances of all classes, forming compounds without number, and presenting every variety of state, appearance and properties. These compounds are often called *oxides*—a name which it is important to remember. Thus, we have oxides of the metals, oxides of sulphur, phosphorus, and a multitude of other bodies, which are again, for the sake of convenience, divided into smaller groups. Very frequently oxygen unites with the same substance in several different proportions, forming as many different and distinct compounds. Its importance cannot be overstated.

The properties of rekindling the taper with red-hot snuff, of not being sensibly absorbed by cold water, and of having no colour or smell, distinguish oxygen from all other known substances.

Hydrogen.—If a small iron tube, as an old gun-barrel, be partly filled with iron filings and placed across a fire so that its middle portion shall be red-hot,

on sending vapour of water through it from a small boiler, a gas will issue from the other end, which, on the application of a light, will take fire and burn with a pale yellow flame. This is *hydrogen.*

In this beautiful experiment, water, which is a compound of hydrogen with oxygen, is decomposed; the oxygen is kept back by the iron, and enters into combination with it, producing oxide of iron, the same substance as that which is found when the watch spring is burned in a jar of oxygen gas. The hydrogen, not having the power of combining with iron, is set free, and escapes. If the tube and filings be weighed before the experiment, and again afterwards, the increase of weight by the addition of this oxygen, will be very evident.

Hydrogen is always procured, when wanted for experiments, by the decomposition of water, which may be effected by easier means than those described. The metal zinc put into dilute sulphuric acid, dissolves, giving off abundance of pure hydrogen. The zinc decomposes the water, combining with its oxygen and rejecting its hydrogen, while the oxide of zinc so produced dissolves in the acid. Iron and some other metals behave in the same way.

Hydrogen is the lightest substance known; hence its use in filling air-balloons. These latter are immense round bags of varnished silk, which, when filled with hydrogen or any other light gas, become capable of rising and floating in the air, even with heavy weights attached. Hydrogen has no smell when quite pure, and is not poisonous; it cannot support life, however. Water does not dissolve it. When set on fire, it burns with a pale yellowish flame, giving much heat, but little light, and reproducing water.

The knowledge of the composition of water is the most important discovery ever made in chemistry, and

happily can be completely proved by exact experiments. When two measures of pure hydrogen and one measure of pure oxygen are mixed in a strong glass vessel, and fired by proper means, a violent explosion takes place, and both gases entirely disappear. The inside of the vessel is found bedewed with pure water, thus formed by the union of the gases in the proportions stated. Now oxygen is, bulk for bulk, exactly sixteen times heavier than hydrogen; the relative weights, therefore, of one measure of oxygen and two of hydrogen must be as the numbers 16 to 2, or 8 to 1. Water, therefore, consists by weight of 8 parts oxygen and 1 part hydrogen. There are other methods, even more exact than this, which lead to the same conclusion.

A mixture of oxygen and hydrogen, made in a common soda-water bottle, and fired by a red-hot wire, or lighted match, explodes with a loud report. A small bladder may be used for the same experiment, being filled with the mixture, the neck tied, and the bladder then pierced by a red-hot rod or wire. A mixture of hydrogen with common atmospheric air explodes when fired, although with much less violence than when pure oxygen is used. All these experiments require great care to avoid accidents.

Perfectly pure water is very seldom met with in nature; even rain-water, the purest of all, contains small quantities of impurity, and that of springs and rivers very much more; for the water in trickling through the ground cannot fail to dissolve out more or less of the various substances it meets with. Sometimes these latter become so abundantly taken up, that the water acquires a strong taste and active medicinal properties; such is the origin of what are called mineral springs. Thus, we have in some parts of the earth springs containing very large quantities of common salt; others

containing salts of magnesia and lime; others in which iron is found; and lastly, the great ocean itself, the water of which is insupportably salt and bitter from the same cause.

Nitrogen.—This is the gas before spoken of as existing in the air and diluting the oxygen so as to moderate its activity and fit it for the proper maintenance of life, combustion, and numerous other offices it has to fulfil. Pure nitrogen is very easily obtained by burning a piece of phosphorus in a glass jar or bottle containing air, standing in a vessel of water; the phosphorus unites with the oxygen of that air, by the act of combustion, withdraws the whole, and leaves the nitrogen.

Nitrogen in the pure state is quite free from smell; it instantly extinguishes flame, and cannot support life. It has never been liquefied or frozen.

Atmospheric air is a mixture of very nearly four measures of nitrogen with one measure of oxygen; it contains, besides, small quantities of other gaseous substances, as vapour of water, carbonic acid, and ammonia. Its composition is always very nearly the same in all parts of the world, and at all heights, from the sea to the top of the highest mountains; and this is a very remarkable fact, since the gases of which air is composed differ in specific weights, nitrogen being lighter than oxygen, and carbonic acid much heavier. They never tend to separate, however, like oil and water, but remain uniformly mixed. This tendency to mix is a property always observed in gases, even under great difficulties; it is a property of vast importance.

The atmosphere, or covering of air about the earth, extends to a great height, 45 or 50 miles, becoming thinner, or less dense, from the level of the sea upwards. This arises from the fact that air and gases in general

are highly *elastic;* they give way under increased pressure, suffering themselves to be readily squeezed into a smaller bulk, and again swelling or expanding when the pressure is diminished. Now the air lying on the surface of the earth and sea, having to bear the weight of all that above it, suffers the greatest amount of compression or squeezing; and this weight becomes less and less as the height increases, and consequently the compression becomes diminished, so that the air in the upper parts of the atmosphere becomes exceedingly expanded.

The weight or pressure of the air at the surface of the earth is very great, being nearly fifteen pounds upon every square inch. The exact pressure is measured by an instrument called a barometer.

The blue sky is really the colour of the atmosphere, which in thick masses always exhibits this tint; in like manner the intense blue of the ocean shows the colour of water, which can only be observed when the water is very deep and perfectly clear.

Atmospheric air is a mere mixture of nitrogen and oxygen; there are, however, not less than five distinct *compounds* of these elements, in which they are combined in different proportions. The most important of these is *nitric acid.* This is commonly obtained by distilling *nitre* or *saltpetre,* with sulphuric acid, and forms a highly corrosive yellowish liquid, which smokes in the air, attacks the skin, and dissolves many metals, as copper, silver, and others.

Carbon.—The only perfectly pure state in which this elementary substance is ever found in nature is that of diamond, this most beautiful and wonderful gem consisting of pure carbon in the crystallized condition. The mineral called *black-lead,* or *graphite,* is also composed of carbon, but less pure, and very different in

appearance and properties. Combined with other substances, carbon is found in great abundance; plants and animals, and substances derived from them, and thence called *organic substances*, always contain carbon, combined with hydrogen, nitrogen, oxygen, and other elements. Carbonic acid exists in the air; united to lime, it forms the numberless varieties of marble, limestone, coral-rock, chalk, &c.

When wood is strongly heated in such a manner that little or no air reaches it, so that it cannot burn and be totally consumed, *charcoal* remains. This charcoal is impure carbon, the hydrogen and oxygen of the wood, with some of the carbon, having been driven off by the heat, and the remainder of the carbon left behind.

Mineral coal, animal bones, and many like substances, treated in the same manner, give a sort of charcoal, useful for various purposes. Soot from oil or tar, *lamp-black* as it is called, is composed almost wholly of carbon. No bodies can be more unlike than lamp-black and diamond, and yet their chemical nature is very nearly the same: the difference appears to arise from the one being crystallized and the other not.

Almost all solid substances, under favourable circumstances, have the power of taking a regular geometrical form or figure, which is accompanied by, and dependent upon, a regular structure. Substances are then said to *crystallize* or form *crystals*, the shape of which is very uniform for the same body, and very often serves as a good distinguishing mark of the substance itself, each having its own particular figure of crystallization. Thus common salt and nitre can be distinguished, the first taking always the square or cubic form, and the second that of a six-sided lengthened figure. That these crystals possess a regular structure, and are built up as it were of rows and layers of very small portions of the

substance in regular order, is proved by the manner in which they cleave or split in particular directions only. Now the act of crystallization is sometimes found to produce a great change in the outward appearance, colour, hardness, and some other properties of substances, their chemical nature remaining the same; and such seems to be the case with the diamond.

Carbonic acid has already been several times mentioned: it is the compound always formed when carbon in any shape is burned in the air or in oxygen gas. It is most easily procured, however, by pouring an acid of almost any kind upon limestone or chalk, when the acid added unites with the lime, and sets free the carbonic acid as a colourless gas, possessing no smell when mixed with air, very heavy, instantly extinguishing a light, and suffocating in a moment any animal which may be plunged into it. These are its most striking properties; in addition it dissolves pretty easily in cold water, and renders lime-water milky by uniting with the lime present. Immense quantities of carbonic acid are constantly produced by our fires and furnaces; fermentation and the decay of animal and vegetable matters also produce it. In respiration of breathing it is abundantly formed. This is the reason why a constant supply of fresh air is required to maintain health and life, and why people suffer so much when crowded in close rooms: —they then breathe poison.

Strange to say, however, this carbonic acid, so fatal to animals, although produced by them, is of the greatest importance to plants, which indeed subsist upon it, absorbing it from the air, and decomposing it by their green leaves in the sunshine in such a manner as to retain the carbon and dispel the oxygen:—a wonderful process, which we can admire, but neither understand nor imitate.

Carbonic acid is composed of 6 parts by weight of carbon and 16 parts of oxygen; by measure it contains its own volume exactly of oxygen.

There is another compound of carbon and oxygen, a combustible gas called *carbonic oxide*, but it is of less importance.

Sulphur.—Sulphur, vulgarly called *brimstone*, is an elementary body of great importance and scientific interest. It is found in the free or uncombined state in the island of Sicily, and elsewhere; in combination with iron, copper, and other metals, in many parts of the world; and in the condition of sulphuric acid, united to lime and magnesia, it exists in gypsum or plaster-stone, and in the bitter salt of sea-water.

Sulphur is a pale yellow, brittle, solid substance, without taste or smell, and a little heavier than water. It melts with gentle heat, and at a higher temperature boils and becomes converted into vapour, that is, if the air be shut out, otherwise the sulphur takes fire and burns. By melting and slow cooling it may be obtained in crystals of very beautiful appearance. It refuses to dissolve in water or spirit of wine.

When sulphur is burned in the air or oxygen gas, it produces a heavy, colourless, suffocating gas called *sulphurous acid*, which is dangerous to breathe, and extremely disagreeable even in very small quantity. This gas is easily dissolved by cold water, and enjoys the curious property of *bleaching*, or destroying many vegetable colours.

A solution of sulphurous acid in water, kept in a bottle imperfectly stopped, loses in a few days its peculiar smell, and becomes sour to the taste. This arises from the absorption of oxygen by the sulphurous acid from the air, and its conversion thereby into a new acid, the *sulphuric*, already referred to, which is never formed

directly when sulphur burns, but is easily produced by the further oxydation, as it is called, of sulphurous acid when dissolved in water. The solution of sulphuric acid obtained in this manner is very weak, but it may be strengthened by boiling it down in a glass or porcelain vessel to a small bulk; water is driven off in vapour, with little or none of the acid, which is much more difficult to volatilize. The strongest acid which can be so got is an oily-looking, colourless liquid, nearly twice as heavy as water, of intensely sour taste, and capable of charring and destroying most vegetable and animal substances. Hence in this state it is poisonous, and requires to be handled with great caution. Sulphuric acid is consumed in immense quantities in the arts, being manufactured on a very large scale by a quicker and easier process than that just described.

In chemical speech, when two acids composed of the same elements are named, the one containing the *least* oxygen is made to terminate in *ous*, and that having the largest quantity in *ic;* as in the foregoing example of the two acids of sulphur.

There are very many other compounds of sulphur, some having an acid character, which the reader will find described in chemical books; many of these are very important and interesting.

The elementary substance *selenium* closely resembles sulphur in its properties; it is exceedingly rare.

Phosphorus.—Phosphorus is one of the most curious and interesting of all the elementary bodies. It is always found in nature combined with oxygen, forming phosphoric acid; this oxygen can be separated by artificial means, and the phosphorus set free. It is a substance much resembling in appearance white wax, soft, and easily melted by gentle heat. In the dark it appears surrounded with a pale luminous smoke, which

continues as long as the phosphorus is exposed to the air, and which is due to a slow and quiet combustion of the phosphorus by the oxygen of the air; to prevent this, it is always kept in water. At a temperature far below that of boiling water, phosphorus takes fire and burns with a large brilliant white flame, producing a cloud of white smoke, which is phosphoric acid itself. The heat of the hand is sometimes sufficient to kindle phosphorus, which then runs about in a melted and blazing state, causing dreadful burns, very difficult to heal; hence the great care required to avoid accidents. The smell of this substance resembles that of garlic. It refuses to dissolve in water or spirit of wine. It is, lastly, extremely poisonous.

There are several compounds of phosphorus with oxygen, all but one of which have acid characters. The most important of these is phosphoric acid. This substance may be procured by various means, as by simply burning phosphorus in dry air, or from minerals which contain it, by a more difficult process. The bones of animals consist in great part of phosphoric acid in combination with lime, and it is from this source that phosphorus is in practice always prepared. As the bones, in common with all other parts of the living body, are constantly renewed, and in childhood and youth grow rapidly in size, a supply of both phosphoric acid and lime in the food becomes necessary, and perhaps the benevolence and wisdom of God are never more strikingly shown than in the care with which this supply is always furnished. In milk, phosphate of lime is found dissolved in a very remarkable manner; grain, roots, animal flesh, and all common articles of food, contain phosphoric acid, the quantity of which is always greatest in those kinds of food which most abound in nourishment. Plants cannot grow without phosphoric acid, the absence of

which renders the soil barren and unproductive, and, accordingly, crushed or even burnt bones are often found to be a most valuable manure.

Phosphoric acid in the pure state, when dissolved in water, forms a colourless liquid, of exceedingly strong acid taste, and in small quantities is not poisonous.

Silicon and *Boron* are elements which may now be noticed. The substances themselves are only to be procured in very small quantities by a long and difficult process; they are important only in their compounds with oxygen, the silicic and boracic acids.

Silicic acid, or silica, is found quite pure in rock-crystal, and nearly pure in the minerals quartz, flint, calcedony, and several others. In combination with some metallic oxides, as alumina, lime, and potash, silica abounds; these compounds will be spoken of in their place. Pure silica, as seen in pounded rock-crystal, is a white, tasteless, gritty powder, quite insoluble in water and acids, but combining with alkalies, both by fusion, and, with greater difficulty, by boiling with a watery solution. Such a compound of silica with an alkali is found in glass, which is made by melting together silicious sand and a proper salt of potash or soda, with the addition of lime or oxide of lead. Silica is also used in making porcelain.

Boron and its oxygen-compound, boracic acid, resemble very closely silicon and silicic acid, except in this particular, that boracic acid dissolves in water, and may easily be had in crystals. It is used in some of the arts.

Chlorine, Bromine, Iodine, and *Fluorine* form a little group or family of elements having a great resemblance among themselves and numerous characters in common; the first is the most abundant and important in practice.

Chlorine is generally prepared by applying gentle heat to a mixture of black oxide of manganese and hydrochloric acid. It is a deep yellow gas, very heavy compared with atmospheric air, and of the most suffocating smell; breathing the smallest quantity causes violent cough and irritation, which sometimes prove very dangerous. It dissolves in cold water, to which it communicates its colour and properties.

The most remarkable feature of chlorine is its power of bleaching or destroying colours of vegetable and animal origin. The most powerful colouring principles, as indigo and madder, are by it broken up and destroyed without the possibility of restoration. Very extensive use is made of chlorine for this purpose in the arts, linen and cotton cloth, and the rags used in the manufacture of paper, being thus rendered white.

Chlorine combines with hydrogen, forming hydrochloric or muriatic acid. When equal volumes of the two gases are mixed in a strong glass bottle, and a light applied, or the bottle exposed for a moment to the sun, an explosion takes place, and the bottle is found filled with a gas which is colourless, very acid and pungent (but much less irritating than chlorine), and which smokes when mixed with moist air. This is hydrochloric acid gas. It dissolves very easily indeed in water, and gives a strong acid solution which dissolves many metals like nitric acid; the solution has been very long known, having been obtained before the gas itself by distilling a mixture of common salt and sulphuric acid. It is of great practical use in chemistry.

Chlorine combines likewise with metals, often with great energy and violence. Copper leaf burns in chlorine; antimony and arsenic in the state of powder thrown into chlorine gas take fire. A lighted taper burns in it for a while with a red smoky flame.

Metallic chlorides, as compounds of metals with chlorine are called, form a very large and interesting class of bodies, many of which are of the greatest practical value. Common salt is one of these, being the chloride of the metal sodium, together with numerous other substances resembling common salt in chemical characters. Chlorine unites also with phosphorus, sulphur, and numerous other elements, including oxygen, and often in several different proportions.

Bromine is a much rarer substance than the foregoing; it is found in small quantities in sea-water, and in certain mineral springs, generally in combination with the metal magnesium. In a pure state it is a deep red and exceedingly heavy liquid, very volatile, and of an odour even worse than that of chlorine. The vapour is red. It dissolves to a small extent in water, and more easily in spirit of wine. In all its chemical characters bromine resembles chlorine in the closest manner, combining with hydrogen and the metals in the same way, often with violence. Thus we have hydrobromic acid, scarcely to be distinguished by its properties from hydrochloric acid, and a long list of metallic bromides.

Iodine is a solid, black, shining, crystalline substance, and so far differs from both chlorine and bromine; its vapour, too, is most remarkable, having an exceedingly beautiful violet colour. In its chemical characters and modes of combination, however, it corresponds with those bodies in the closest possible manner; even in smell it resembles them, but is less powerful and offensive. Iodine is found in sea-weeds, and in very small quantities in sea-water.

Fluorine is the last member of the group. Very little is known of this element in the separate state. Its chief source is the beautiful mineral called fluor spar,

which is the fluoride of the metal calcium, and its most interesting compound its hydrogen acid, which is procured by distilling fluor spar in powder with sulphuric acid in a retort of platinum. This acid enjoys the extraordinary property of dissolving glass.

ON CERTAIN COMPOUNDS FORMED BY THE UNION OF THE PRECEDING BODIES AMONG THEMSELVES.

Several exceedingly interesting compounds, in addition to those already mentioned, are formed by the union among themselves of the non-metallic elements, as *carburetted, sulphuretted,* and *phosphuretted hydrogen* and *ammonia.* There are two kinds of carburetted hydrogen gas, the one called light carburetted hydrogen, and the other olefiant gas. Both are produced indirectly; carbon and hydrogen cannot be made to combine by direct means, like carbon and oxygen.

Light carburetted hydrogen is often formed naturally. If the mud of a stagnant reedy pool be stirred, bubbles of gas will be observed rising to the surface, which takes fire on the application of a light and burns with a bright flame. Beds of coal often disengage this gas from natural cracks and openings, and on being pierced by the hand of man; the air of coal-mines thus often becomes explosive by a large admixture of this gas, so that it takes fire by the miner's candle, and the unfortunate workmen perish in a blast of flame, or are suffocated by the carbonic acid produced. By artificial means light carburetted hydrogen can also be procured, namely by strongly heating in a flask or retort a mixture of acetate of soda, hydrate of potash, and quick-lime in powder. When pure, the gas has no odour; it is much lighter than atmospheric air, although heavier than hydrogen itself. When kindled, it burns with a tolerably

bright yellowish flame, producing water and carbonic acid gas, thus showing its composition, which can be proved exactly by mixing it with a known measure of pure oxygen in a suitable glass tube, firing the mixture, and then observing the alteration of bulk undergone by the gas, and the quantity of carbonic acid produced *.

In all the large towns of Europe and America a gas is manufactured from coal for the purpose of lighting streets and houses, which is thus done very safely and effectually and at small cost. The coal is exposed to heat in large iron retorts, and the gas, which is produced in very great abundance, cooled, to separate vapour of water, tar, and other substances formed at the same time, and, being further purified by passing through a mixture of lime and water, is received into immense iron vessels suspended in tanks of water, where it remains until wanted. From these gas holders it is carried by suitable pipes to the street lamps and into the houses, where it is burned. Now this gas consists in great measure of light carburetted hydrogen, mixed, however, it is thought, with olefiant gas, and with smaller quantities of other gases, very difficult to separate and to study.

In some parts a most excellent gas for the same purpose is made from oil, the latter being made to drop slowly into a red-hot iron retort, from which the gas is conveyed away to the gasometer, no purification being required. Oil gas is very much better than coal gas, and gives more light when burning, but is expensive.

Olefiant gas can only be obtained pure from spirit of wine, or one or two other substances derived from spirit; it is commonly made by heating in a flask or retort a mixture of strong spirits of wine and sulphuric acid, and passing the gas through water, solution of

* All these operations must be seen to be understood; it is useless, therefore, attempting a full description.

potash, and strong sulphuric acid, in succession, to separate certain impurities. It is colourless, and a little lighter than air; it has a faint garlic smell, and burns with a very bright white flame, forming water and carbonic acid. The name olefiant, meaning oil-making, was given from the fact that this gas, when mixed in a glass jar with chlorine, slowly combines with the latter. When quickly mixed with a large quantity of chlorine, and set on fire, it burns with a red flame, and an abundant deposit of black soot. The chlorine combines with the hydrogen of the olefiant gas to form hydrochloric acid, and the carbon is set free.

All common combustible substances, used to produce heat and light, as coal, wood, oil, tallow, and wax, consist of carbon and hydrogen, with a certain proportion of oxygen; they consequently all produce carbonic acid and water in burning. In the flame of a candle, carefully observed, a number of interesting things may be seen. The melted fat is first sucked up by the porous wick, then converted by the heat into combustible gases which take fire and form the flame. As burning can only go on where oxygen is present, the flame must really be hollow, since the middle portion consists of highly-heated inflammable gas, ready to take fire, but unable to do so for want of a supply of oxygen, which cannot for the moment reach it. And this hollow character belongs to all flames burning in the air.

Very intense heat is got in furnaces used for melting glass, metals, and many other purposes, by increasing the rapidity with which the fuel is consumed by the introduction of a rapid current of air, which is either forced through the fire by bellows or other machines, or drawn through by the draught of a tall chimney. In this manner, more fuel being burned in the same time, the temperature produced by combustion, in other

words, the intensity of the heat caused by the combination of the carbon and hydrogen of the fuel with the oxygen of the air, becomes greatly increased. The forms of furnaces are as varied as their uses and applications, but the general principle is the same in all.

Sulphuretted hydrogen is most easily obtained by pouring diluted sulphuric acid upon sulphuret of iron, which in its turn is prepared by heating together filings of iron and sulphur. It is a colourless gas, of the most offensive odour, namely, that of rotten eggs, which in fact emit sulphuretted hydrogen. It is very poisonous when breathed, although not irritating. When set on fire, it burns with a blue flame, forming water and sulphurous acid. Many metals, as silver, copper, and lead, are attacked and blackened by this gas; white paint, which is a preparation of lead (carbonate of the oxide), is thus spoiled by the sulphuretted hydrogen formed by putrefaction in drains and in the holds of ships, where animal and vegetable matter is in the act of decay. In warm countries especially, this is a sign which should never be neglected, for in such processes subtle poisons are generated with the sulphuretted hydrogen, infinitely more dangerous than the latter, which, if unchecked, spread fever, pestilence, and death. Fumigation with chlorine, which instantly destroys sulphuretted hydrogen, and probably acts as energetically upon the poisonous principles spoken of, may in some cases be useful; but the remedies most to be depended upon, as a general rule, are cleanliness and ventilation, a copious supply of fresh water and pure air.

Sulphuretted hydrogen is constantly used in the laboratory to throw down in an insoluble state, or *precipitate*, certain metals from solution, which it often does in a manner so peculiar and striking as to mark and distinguish the nature of the metal most perfectly.

Phosphuretted hydrogen is also a colourless invisible gas, procured by several easy processes; its smell is quite different from that of sulphuretted hydrogen, but still very disagreeable, resembling that of phosphorus itself, but more powerful. It is very inflammable, and burns with a bright flame, yielding water and phosphoric acid. Sometimes this gas is spontaneously inflammable, that is, takes fire of its own accord when admitted into the air. This property is not enjoyed by the pure gas, but is due to the presence of a small quantity of the vapour of an exceedingly volatile liquid compound of phosphorus with hydrogen, which is now and then produced with the gas itself.

Ammonia is the last of these compounds to be mentioned, but certainly one of the most important. It is composed of nitrogen and hydrogen. Like carbon and hydrogen, however, these two bodies never unite directly; ammonia is only formed when its elements are presented to each other in the peculiar state in which they exist when just set free from combination, as when animal and vegetable substances containing carbon, hydrogen, nitrogen, and oxygen, are decomposed and destroyed by putrefaction, or by heat in a close vessel; a great part of the nitrogen under these circumstances, by combining with those of the hydrogen, takes the form of ammonia.

Ammonia is a colourless gas, much lighter than air, and having an exceedingly pungent and powerful smell. It is instantly dissolved by water, so that experiments over water cannot be made with it in the manner usual with gases, as oxygen and hydrogen, which dissolve but sparingly. Indeed water takes up in this manner not less than 500 or 600 times its own bulk of ammoniacal gas. The solution has long been known under the name of *spirits of hartshorn.* Solution of ammonia

possesses in a high degree alkaline properties, restoring, like potash and soda, the alkalis proper, the blue tint of vegetable colours which have been reddened by an acid, and forming salts by combining with the different acids themselves. The exact composition of ammoniacal gas can be demonstrated or proved by a very beautiful and simple experiment, namely, to cause it to pass several times through a red-hot porcelain or iron tube, taking care that nothing escapes. The bulk of the gas is found to be doubled, its pungent smell is gone, and it has all the characters of a mixture of nitrogen and hydrogen, containing one measure of the former gas to three of the latter. The compound has been resolved into a mere mixture, and this by the simple application of heat.

Traces of ammonia exist in the atmosphere; it there performs an important duty in the maintenance of the life of plants, namely, that of furnishing the nitrogen they require, in the wild state at least, for forming the seeds and other parts which contain that element.

ON THE GENERAL PRINCIPLES OF CHEMICAL COMBINATION, AS ILLUSTRATED BY THE HISTORY OF THE SUBSTANCES DESCRIBED.

It is hoped that the following remarks may serve as an introduction to the study of this part of chemical science, and excite the desire for more precise and extended information.

Chemical combinations always take place in a certain fixed and regular manner; they follow rules or laws, simple and few in number, which never change, and which govern the formation of compounds of all classes and descriptions.

When bodies combine, it is always in fixed and de-

finite quantities or proportions by weight; in other words, the same compound substance, however formed or produced, always contains the same elements united in the same proportions. Thus, water may be formed in a great variety of chemical changes or reactions; but however produced it still consists of oxygen and hydrogen in the proportions of 8 parts of the former to 1 of the latter by weight; and this is true of all compounds whatsoever.

The same substances often combine in several different proportions, forming a chain or series of compounds closely allied. When this occurs, a remarkable and beautiful relation may be traced between the proportions of the second element which unite with the first, the quantity of the latter being supposed to remain constant. The compounds of nitrogen with oxygen furnish an excellent example of this law in its simplest form; they are five in number, named as below, and differ greatly in properties. The first is a permanent gas, capable of supporting combustion, and possessing an extraordinary intoxicating power; the second is also a gas, colourless and invisible, which on contact with air gives rise to a deep red vapour of a very irritating nature; the third is an acid, capable of forming salts; the fourth is a very volatile neutral substance; the fifth is the nitric acid, before spoken of, by far the most important member of the series.

	Proportion of Nitrogen.	Proportion of Oxygen.
Protoxide of nitrogen	14	8
Deutoxide of nitrogen	14	16
Hyponitrous acid	14	24
Peroxide of nitrogen	14	32
Nitric acid	14	40

Retaining the same proportion of nitrogen in all the

compounds in the series, the quantity of oxygen is seen to increase by *multiples* of that of the first, the second containing twice, the third three times, the fourth four, and the fifth five times as much oxygen compared with the nitrogen as the first on the list. There are no intermediate compounds whatever. And this law is perfectly general; whenever bodies combine in more than one proportion, a relation of this kind between the quantities concerned can be observed. It applies alike to elementary substances and to compounds formed by the union of bodies themselves compound. The series of numbers may, however, be incomplete, or the relation of the numbers not quite so simple as that in the case cited.

The first of the laws of chemical combination, therefore, will be the constancy of composition of the same substance however produced; and the second, the law of multiple proportions. The third law, called the *law of equivalent quantities*, is perhaps rather more difficult to understand, but infinitely too important to be neglected. It will be best to give an example of its application.

An elementary substance is chosen whose range of combination is very great; that is, it unites in a definite manner with most of the other elements, forming compounds which can be easily and thoroughly examined by experiment, and their exact composition ascertained and put down in a table in such a manner as to show the relative quantities of the other elementary bodies which combine with one and the same quantity of that so chosen. The most suitable substance for this purpose is oxygen, and the most convenient quantity to choose, 8 parts by weight. The quantities of hydrogen, nitrogen, carbon, sulphur, metals, &c., found by experiment to unite with 8 parts of oxygen, will stand thus:—

Oxygen	8
Hydrogen	1
Nitrogen	14
Carbon	6
Sulphur	16
Phosphorus	31
Chlorine	35
Iodine	126
Iron	28
Silver	108
Lead	104

Now the law is to this effect:—These numbers show the relative proportions in which the different bodies named combine with oxygen; but something more:—they show the proportions *in which the bodies combine among themselves.* No combinations can take place among the elements but in these proportions, or multiples of them. For example, hydrogen and chlorine combine to form hydrochloric acid in the proportions of 1 to 35; hydrogen and sulphur, 1 to 16; chlorine and silver, 35 to 108; iodine and lead, 126 to 104; hydrogen and nitrogen to form ammonia, 3 (the multiple of 1) of the former to 14 of the latter, &c. The numbers represent quantities of matter of the elements *equivalent* to each other in every way, and capable of exactly and mutually replacing each other in combination; hence they receive the name of chemical equivalents.

There is, lastly, a fourth law which states that the equivalent or combining quantity of a compound is the sum of the equivalents of its components. It is not necessary in this little work to enter further upon the subject, although the proof is very easy to give.

These four laws comprehend all that relates to combination by weight; there is another point, however, of

great interest, namely, the law of combination by measure or volume among gases.

When gases combine, which is very often the case, it is always by measures which have a simple relation to each other; as equal measures; one to two; one to three. Examples may be found in chlorine and hydrogen, oxygen and hydrogen, nitrogen and hydrogen. With compound gases, and the vapours of volatile substances, the same fact is observed; the volumes are always equal, or multiples the one of the other. Now the cause of all this is simply the wonderful relation or connection which has been established between the specific weight of a gas or vapour and its volume, by which the quantities of matter required for combination occupy in the gaseous state either the same volume, or the double or triple the one of the other*.

THE METALS.

The metals form the larger group of elementary substances, but, as already remarked, their importance is exceedingly unequal, many of them being excessively rare.

In the Table of Elementary Substances the list of metals (page 4) is numbered with a view of separating it into divisions, each containing a class of metals resembling each other in many points, or having many characters in common. This classification will now be found very useful.

The first class embraces the metals of the alkalis, potassium, sodium, and lithium. Potassium in the metallic state is procured by very strongly heating in an

* The pupil must not feel discouragement if much of the above is yet unintelligible to him; general laws are always more difficult to understand than particular facts. It is only by gradually increasing knowledge of the latter that the laws themselves become understood.

iron bottle or retort a mixture of dry carbonate of potash and charcoal. The salt is decomposed with production of a large quantity of inflammable gas (carbonic oxide), and the potassium distils over in vapour, which is condensed in a particular manner, so as to exclude the air. It is a brilliant white metal of the colour of silver, very soft, and easily melted. Exposed for an instant to the air, it tarnishes and becomes covered with a crust of oxide. Its attraction for oxygen is indeed so powerful that it decomposes water with violence, combining with the oxygen to form potash, and liberating the hydrogen. When thrown upon the surface of water, it instantly takes fire, burning with a beautiful purple flame, and yielding a solution of potash. Another remarkable character of this metal is its small specific weight, being considerably lighter than water. It combines directly with chlorine and a number of elementary substances, forming compounds which in many cases possess considerable importance.

Potash, or oxide of potassium, is found in great abundance, in combination with silica and silicate of alumina, in the mineral called felspar, which is the chief component of granite, a rock very extensively distributed over the earth, and of all those rocks which have a volcanic origin. By long exposure to the air and weather such rocks decay or disintegrate and form soils in which plants grow. By the decay of the rock, the potash which before existed in the state of silicate, nearly unaffected by water, becomes gradually brought into a soluble condition, absorbed by the roots of the plants, and accumulated in the leaves and other parts, in combination with a vegetable acid formed by the plant itself. When the plants are burned, this vegetable acid is destroyed, and the potash left in combination with carbonic acid, giving rise to carbonate of potash, easily extracted by water

from the soluble portion of the ash, and from which potassium itself, and all its compounds, are easily prepared. It is found far better to take advantage of the potash salt, drawn from the soil by vegetables, than to attempt its extraction directly from felspar. In what way this substance contributes to the growth and nourishment of plants yet remains unknown; it is certain, however, that they cannot live without it, and that a soil destitute of potash is always barren.

Many of the salts formed by the union of potash with the different acids are of great practical use; in addition to the carbonate, which is largely employed in making glass and for other purposes, we have nitrate of potash, from which nitric acid and gunpowder are prepared, and other valuable compounds of this alkali.

Sodium is a metal very much resembling potassium, and obtained from carbonate of soda by like means. It is not quite so oxidable as potassium, but decomposes water with energy, although it seldom inflames when thrown on the surface of that liquid. The salts containing this metal are very numerous and of great value; at the head of these stands common salt, which is the chloride of sodium. The waters of the ocean contain immense and incalculable quantities of this substance, which is also found in many parts of the world forming beds of wonderful thickness and extent in the earth, as rock salt. From common salt carbonate of soda is made by a somewhat complicated, but not difficult process, and from the carbonate, all the other salts, by the addition of the proper acid; for carbonic acid possesses so feeble an attraction for metallic oxides, that carbonates are decomposed by almost every acid, and salts of every description are thus easily got if the carbonate of the oxide be once obtained.

Carbonate of soda is used in enormous quantities in

making soap and some kinds of glass, and for other purposes. Several of the other salts are also of considerable value.

Lithium is a very rare metal; its oxide, lithia, is only found in a few scarce minerals, and in minute quantity, in the water of certain springs.

The metals of the next group, Number II. in the Table, (page 4) bear the name of metals of the alkaline earths. The metals themselves are procured with great difficulty, and in very small quantities; their oxides, baryta, strontia, lime, and magnesia, are well-known substances, the two latter being of great importance. Baryta and strontia are chiefly found as carbonate and sulphate in lead mines; they accompany the lead ore. Carbonate of lime forms immense beds and mountain masses in all parts of the world, in the various forms of marble, limestones, chalk, and coral, which differ chiefly in texture and appearance. Sulphate of lime, called gypsum or plaster-stone, is also sometimes abundantly met with. Magnesia occurs in two states, namely, as carbonate in certain limestones, being there mixed with carbonate of lime, and as sulphate and chloride in sea-water, and that of many mineral springs.

The origin of most of the common limestones is very remarkable and interesting. They are made up of the remains of shell fish and coral animals which lived in ancient seas, now become dry land, where each generation contributed its share to the bed of shells spread over the bottom, which gradually and in the course of ages acquired great thickness and solidity, and, being at last raised above the surface of the water by a power acting from beneath, became hardened into a rock by the slow infiltration of water holding carbonate of lime in solution, or by the more rapid and powerful effect of volcanic heat. There are few limestones, except the

purest and most crystalline marbles, in which the shells and corals cannot yet be seen in a condition more or less perfect, and it is thought that marble itself forms no exception, as it has clearly been subjected to the action of heat, which would melt and obliterate the forms of such remains.

When limestone of any kind is made red hot in the open fire, the carbonic acid is driven off and quick-lime remains. The most familiar property of this substance is that of *slaking*, on the addition of water; it combines with the water forming a definite compound or hydrate, in the shape of a soft, dry, white powder. Great heat is produced in the act of combination, sufficient sometimes to char wood, for ships carrying lime have been often set on fire by water reaching the cargo in bad weather. Pure baryta and strontia enjoy the same property of combining violently with water: a property which is exhibited by magnesia to a much feebler degree.

The hardening of mortar, made with slaked lime, sand, and water, is caused by its gradual absorption of carbonic acid from the air. This change is, however, extremely slow; but, if time enough be allowed, the mortar at last acquires the hardness of stone;—a state exhibited by the mortar of many ancient buildings in Europe.

The metals of the earth proper, group Number III., are more numerous than those of either of the foregoing sections; there is only one of them, however, aluminum, of sufficient importance to require description; the others are only found in rare minerals. Metallic aluminum is difficult to obtain; it has the colour of iron, does not tarnish in the air or decompose water, but burns when heated, yielding its oxide, alumina. The latter is one of the most important substances in nature, inasmuch, as already remarked, it enters into the

composition of felspar and other like minerals, which in one state or other contribute largely to make up the mass of the earth. The alumina in all these cases is found in combination with silica or silicic acid; felspar, in chemical speech, would be termed a double silicate of alumina and potash. All the numerous varieties of clay, shale, and slate, are produced by the decomposition of felspathic rocks. When the felspar is pure, white clay results, fit for the use of the potter; when the rock contains much oxide of iron, the clay is yellow, brown, or red, and fit only for coarser purposes.

The most important of the soluble salts of alumina is alum, or double sulphate of alumina and potash. This is an extremely beautiful salt, forming large regular crystals. It is manufactured on a great scale for use in the arts, especially in dyeing.

The group of metals numbered IV. contains several of very great practical value; it includes, among others, iron, copper, zinc, and lead. Unlike those of the three foregoing sections, the metals of this group are familiar to us in the pure state; they are reduced from their oxides or other natural and artificial compounds with comparative ease, and do not show such a tendency to oxidation as to render their preservation when obtained at all difficult. Two of them, indeed, sometimes occur in the earth in the metallic state.

Another peculiarity is their mode of distribution. The oxides of aluminum, calcium, and potassium, in combination with silica or carbonic acid, form immense beds and masses of rock, which frequently rise into lofty mountain chains, or form the surface of large tracts of country. The metals of the present and of the succeeding groups, on the contrary, are, with the exception of iron, found only in mineral veins traversing the granitic, slate, or limestone rocks. These veins present

somewhat the appearance of having been at one time cracks or fissures in the rock they run through, afterwards filled up with new matter. It is in such formations that the greater number of metals are found. The oxide of iron is found, however, in greater or less quantity in every situation; great beds of it occur among the wooded mountains of Sweden and Russia, and in the coal formations of England, and these furnish all the iron of commerce.

The oxides of the metals of this division form for the most part beautiful crystallizable salts with acids, which is one of their most striking chemical characters.

Group V. Of these metals tin and antimony alone require mention; the others are very rare, or not applied to any useful purpose. The county of Cornwall in England has been for many ages celebrated for producing tin, which is found in few places besides. The softness, white colour, and other properties of tin render it one of the most useful of the metals; it combines with copper and lead, forming compounds or alloys of great value, and with iron, in tinned plate, of which cooking vessels and other articles are made. Antimony is a tolerably abundant metal, of gray colour and remarkable brittleness. In combination with lead, it forms the type metal of the printer, and some of its compounds are employed in medicine.

Group VI.; noble metals. The term noble is a fanciful expression referring to the comparative unchangeableness of the metals of this class, many of them resisting oxidation even in the fire, and having their oxides brought to the metallic state by the simple action of heat. Gold and platinum are always found in the metallic state in the earth; silver and mercury very frequently. The value and uses of some of these metals are well known, and depend in great measure on this power of resisting

the action of oxygen and other chemical agents. The most curious of them, perhaps, is mercury or quicksilver, from the circumstance of its being fluid at all common temperatures, and requiring intense cold for solidification. Metallic mercury is used in the construction of many scientific instruments; an alloy of mercury and tin covers the backs of mirrors, while many of its salts and other compounds are of great value in medicine. The metal platinum is highly esteemed by the chemist, who finds vessels of platinum of the greatest service in his experiments. They resist the greatest heat of a furnace, and are attacked by very few of the substances used in chemistry.

Arsenic and tellurium are bodies which have characters intermediate between those of the metals and certain of the non-metallic elements, as phosphorus and sulphur. Arsenic is a gray, metallic-looking, brittle substance, occasionally met with pure, and abundantly in combination with iron and other metals. When these latter compounds are exposed to heat in the air, the arsenic and the metal suffer oxidation together, and the former is volatilized in the shape of arsenious acid, which condenses as a white solid substance, the *white arsenic* of commerce, but too well known as a most dreadful poison. It is used in making green paint, and for a few other purposes.

Tellurium much resembles arsenic, but is exceedingly rare.

ON THE NATURE OF SALTS.

The term Salt, or saline combination, is applied in chemistry to a great variety of substances in a manner which it is necessary to explain.

All compounds containing a metallic oxide united to an acid, whether they be soluble in water or not, are

called salts of that oxide;—thus we have nitrate of potash, carbonate of soda, sulphate of baryta, acetate of oxide of lead, &c., &c., formed by the union of the oxides of potassium, sodium, barium, and lead with the nitric, carbonic, sulphuric, and acetic acids. Such metallic oxide is termed the *base* of the salt, which thus consists of a basic substance and an acid.

All compounds containing chlorine, iodine, bromine, or fluorine in combination with a metal, whether they be soluble or insoluble in water, crystallizable or not, are also called salts, although they consist of two elementary substances only, and thus differ completely from the salts of the first class, which consist of a base and an acid, both of which are oxides, the one basic, the other acid. Chloride of sodium or common salt, iodide of potassium, and fluoride of calcium or fluor spar, are examples of salts of the second class, which are said to consist of a metal in combination with a salt-radical, which is a term given to chlorine, iodine, &c.

There are other substances not comprehended in the above description to which the term salt is given, but they need not be now considered.

Thus, we have two distinct classes of salts, namely, oxygen-acid salts, like nitrate of potash or sulphate of soda, and salts formed on the plan of common salt, containing a metal and a salt-radical only. Between the members of these two classes the greatest resemblance exists; indeed there is nothing in their appearance or characters to point out so great a contrast of constitution.

All metallic oxides are not necessarily basic; certain of them only enjoy this property, others refusing to unite with acids altogether. When a metal forms several compounds with oxygen, only one among these commonly possesses the power of forming well-defined

salts with acids; and, if a second base occur at all, its powers are weak and feeble in this respect. Those metallic oxides in which the basic power is most strongly marked, that is, whose tendency to form with acids regular, definite, and often crystallizable compounds, is exceedingly energetic, possess, when they happen to be soluble in water, the power of acting on certain vegetable colours in a remarkable manner, and one quite opposed to that exerted by acids. Thus litmus, a blue dye of this description, is rendered red by an acid of almost any kind, while its blue tint is restored by the basic metallic oxides in solution. Potash and soda, and, to a certain extent, yellow oxide of lead, thus restore the colour of reddened litmus. The effect is called *alkaline reaction*, as opposed to acid reaction; potash and soda long ago received the name of alkalis, from an Arabic word meaning bitterness.

In well-defined crystallizable salts, containing a strong base in combination with a strong acid, the reactions of both disappear; a solution of the salt ceases to affect vegetable colours at all. It is then said to be neutral. Accordingly, in practice, when it is necessary to neutralize a base by an acid, or an acid by a base, paper stained with litmus in the blue and red states is used to ascertain that no excess of either one or the other remains, or has been added. Such test papers are easily prepared, and are of indispensable use in chemistry.

There are a great number of interesting matters connected with the formation and constitution of salts, which the pupil will find described in regular works on chemical science, but which cannot with advantage be here discussed.

ON ORGANIC SUBSTANCES.

By organic substances are understood definite com-

pounds, obtained, directly or indirectly, from plants and animals having a peculiar chemical nature and constitution, in virtue of which they form an immense group or family, having many features and properties in common, although in other respects they may differ widely among themselves, some being acid, some basic, and many exhibiting but little tendency to combination at all. They all consist of carbon in combination with hydrogen, or with hydrogen and oxygen—or with hydrogen, oxygen, and nitrogen. In a few cases sulphur and phosphorus are present, and by indirect means compounds of this kind can be procured, containing chlorine, iodine, sulphur, and other elements. No such bodies, however, occur ready formed in nature; those there met with never contain more than five elements, and the greater number only three, one of which is always carbon.

With the exception of a few substances, such as woody fibre, starch, and gum in the vegetable kingdom, and certain complicated compounds containing much nitrogen and sometimes sulphur which occur in plants, and form the most important components of the animal frame, organic bodies when in the solid state enjoy the faculty of crystallizing, which is at all times a character of the greatest value both in the preparation and study of these substances, inasmuch as it gives in most cases a proof of unity of nature and freedom from admixture. With volatile organic liquids, which do not crystallize at a low temperature, we have in the boiling point an indication of almost equal importance. When this remains constant during distillation, almost certain proof is obtained that one substance only is present.

It is impossible, in the compass of a few pages, to give any distinct account of the vast numbers of organic compounds already known to chemists; every year

large additions are made to the list, and bodies described possessing properties and relations the most interesting that the imagination can conceive. The means of inquiry and investigation have been brought to a state of wonderful simplicity and perfection, and every step gained increases the hope that in the end many of the mysteries of animal and vegetable life may be made clear to the eye of science. We are already permitted to see more or less perfectly many links of this wonderful chain of actions; we see the carbonic acid, water, and ammonia, bone earth and the alkalis, restored to the air and the earth by the breathing of the animal during life, and by the decay of its body after death, employed in forwarding the growth and maintenance of another and different race of organic beings, the vegetables namely of the field and forest, which under the influence of the sun's light decompose this carbonic acid and ammonia, restore a great part of the oxygen to the atmosphere, and employ the remaining elements in the formation of those complicated products of organic life which art yet in vain endeavours to imitate. Life and death succeed and are dependent upon each other; the individual perishes, but the race remains. To be permitted to point out the means by which the Creator has been pleased to accomplish his wonderful works in the living world, and to discover and make known the various intermediate steps and processes between the two extremes, is the present task of Organic Chemistry.

APPENDIX.

ON THE APPLICATION OF CHEMISTRY TO AGRICULTURE.

THE study of organic chemistry is calculated forcibly to remind the inquirer of the awful sentence pronounced on man at the fall, "In the sweat of thy face shalt thou eat bread, till thou return unto the ground; for out of it wast thou taken: for dust thou art, and unto dust shalt thou return."—Gen. iii. 19. The food of plants consists entirely of inorganic matter, or of matter rendered inorganic by decomposition; the food of animals is for the most part organic, and even those animals which are entirely carnivorous may be said to derive their food from plants, since their prey is herbivorous. "Man and animals receive the constituents of their blood and of their bodies from the vegetable world; and an Infinite Wisdom has so ordained that the life and luxuriance of plants are strictly connected with the reception of the same mineral substances that are indispensable for the development of the animal organism; without the presence of the inorganic matters found in the ashes of plants, the formation of the germ, leaves, blossoms, or fruit, could not be effected."—*Liebig.*

I.—THE ELEMENTS OF PLANTS, AND THE SOURCE OF THEIR CARBON.

A living plant and a living animal may each be compared to a chemical laboratory, in which compound bodies are analyzed or separated into their component parts, and recompounded into other substances distinguished as *vegetable* or *animal* products.

These products usually consist of two distinct portions, the *organic* and the *inorganic*. The former constitutes the great bulk of the substance in its dry state; the inorganic portion varies from 1 to 10 per cent. by weight of the whole substance. The organic portion is capable of being separated from the inorganic by the action of fire; the one is said to be destroyed, the other remains behind in the form of an ash.

The organic portion consists of a very limited number of elements: carbon, hydrogen, oxygen, and nitrogen, combined in some cases with minute quantities of sulphur or phosphorus, form the brief alphabet with which Nature has written the history of the vegetable kingdom.

Carbon, oxygen, hydrogen, and nitrogen exist in the organic part of plants in very different proportions. For example, in all vegetable products used as food and in the dry state, the carbon amounts to nearly one-half by weight of the whole substance, the oxygen to rather more than one-third, the hydrogen to little more than 5 per cent., and the nitrogen to from 2 to 4 per cent.

Plants derive these elements from their food, which enters partly by the roots and partly by the pores of the leaves and of the young twigs; in other words, the roots feed on the soil, the leaves on the air.

In a perfect plant, such as a tree, the root is of considerable size, consisting of distinct arms, from each of

which proceed innumerable fibres; the trunk or stem rises to a considerable height in the air, sending out numerous arms, branches, and twigs, for the purpose of multiplying leaves, and thereby exposing a large amount of surface to the air.

The stem of a tree consists of three portions, namely, a central pith, the wood surrounding the pith, and the bark covering. The pith is occupied by a number of minute cells, which are supposed to communicate with the air horizontally through the medullary rays of the outer bark. The wood and inner bark form a series of long vertical tubes, which convey liquids up and down between the root and the leaves. The branches and thick parts of the root have a similar structure to the trunk or stem, but as the root tapers away the pith disappears; the bark thins out, the wood softens, and at its extremity a porous spongy mass is formed, in which the minute tubes of the stem and root terminate. These spongy extremities of the roots connect the soil with the leaves, so that both root and leaves mutually assist each other's functions.

The leaf is an expansion of the twig; the fibres at its base are prolongations of the vessels of the wood; the green exterior is a continuation of the inner or cellular tissue of the bark; this green portion is full of pores, especially on the under surface, and it also consists of a collection of tubes or vessels extending along the surface of the leaf, and communicating with those of the inner bark.

All the vessels of a tree are full of sap, which rapidly circulates during the season of vegetation; in winter, its motion is scarcely perceptible, but, unless frozen, it is never stationary. The sap ascends from the spongy part of the root, through the vessels of the wood, until it is diffused over the interior of the leaf by means of

its woody fibres; then, by means of the vessels beneath these fibres, it is returned to the bark, and descends to the root through the vessels of the inner bark. The spongy fibres of the root are constantly extending their limits, wandering, as it were, in search of pasture; the food which they take up from the soil must be in a state of solution, and this is sent with the sap to the upper parts of the tree.

The leaves, the green stem of young shoots, and the green stalks of grasses, inhale their food in a gaseous state. By day they absorb carbonic acid, decompose it, retain the carbon, and give off oxygen. At night the process is reversed, oxygen being absorbed and carbonic acid exhaled*; but as this process is not so rapid as the former, plants gain a large portion of carbon from the atmosphere, which varies with the season, the climate, the soil, and the kind of plant. It is calculated that from one-third to four-fifths of the entire quantity of carbon in the crops of our climate, growing on land of average fertility, is obtained from the air.

But the carbon of plants is also partly supplied by the roots as well as by the leaves. This is furnished by the *humus*† or decaying vegetable matter of the soil, which undergoes several changes before it is in a

* This property of absorbing oxygen also belongs to fresh wood, whether taken from a twig or from the inner trunk of a tree. When fine chips of such wood are moistened and placed under a jar of oxygen, the gas diminishes in volume. But wood dried in the air and then moistened, converts the oxygen into carbonic acid without change of volume. "When villages situated on the banks of rivers become inundated with floods, this property of wood gives rise to much disease. The wood of the floors and rafters of the building become saturated with water, which evaporates very slowly. The oxygen of the air is absorbed rapidly by the moist wood, and carbonic acid is generated. The latter gas exercises a directly pernicious influence when present in air to the amount of 7 or 8 per cent."—*Liebig.*

† From the Latin *humus*, the moist earth, or soil.

fit state to supply carbon to the plant. By the gradual absorption of oxygen from the atmosphere, carbonic acid is at length formed, and this supplies the plant with carbon food. The humus does not, on account of its insolubility, directly contribute food to the roots of plants. If humus were soluble, it would be liable to be washed out of the soil by heavy rains; but by slowly yielding to the action of heat, moisture, alkalis, and other chemical agents, it becomes a gradual and continued source of carbonic acid. During the decomposition of woody fibre, water and mould or humus are formed, as well as carbonic acid. According to Saussure, 240 parts of dry sawdust of oak wood convert 10 cubic inches of oxygen into the same quantity of carbonic acid, which contains 3 parts by weight of carbon, while the weight of the sawdust is diminished by 15 parts. Hence, 12 parts by weight of water are at the same time separated from the elements of the wood. Heavy soils, consisting of loam, retain moisture for a length of time, and thus promote the decay of vegetable matter; but they do not freely admit the air. In moist sandy soils, particularly such as contain carbonate of lime, decay proceeds rapidly, it being greatly favoured by the alkaline lime.

It frequently excites the surprise of persons who approach this subject for the first time, that the carbon of plants, which forms the great bulk of forest trees, and a large portion of every vegetable, should be obtained from an invisible gas floating in the air in small quantity, and lying dissolved in the juices of the soil. If we bury a piece of wood in a crucible filled with sand, and raise the whole to a red heat in the fire, the juices of the wood will all be dissipated. When the crucible and its contents have become cold, a piece of black charcoal will remain, of the same size as the wood

originally employed, but very much lighter. This charcoal is the carbon of the wood, not quite pure, because it contains the mineral portions, which form a small but important addition to plants. Now, it is perfectly easy to convert this black carbon into an invisible gas, into the state in which it furnishes food to the plant. By burning it in oxygen gas it disappears, uniting with the gas to form carbonic acid; but this is only one out of many methods by which carbonic acid is formed in the atmosphere; every fireplace, every lamp and candle, contributes a supply of carbonic acid to the atmosphere: or, in other words, in the act of combustion the carbon of the combustible unites with a portion of the oxygen of the air to form carbonic acid. The respiration of animals effects the same change, for respiration is only a slow combustion, the carbon which is disengaged from the venous blood uniting with oxygen in its passage through the lungs, and forming carbonic acid, which is discharged by the mouth and nostrils. A man consumes by respiration from 20 to 25 cubic feet of oxygen in 24 hours. During the germination of seeds oxygen disappears, and carbonic acid is produced; the same thing occurs during fermentation and the conversion of the constituents of the soil into the carbon food of plants.

But notwithstanding all these sources of vitiation, the composition of the atmosphere, in respect of its principal ingredients, continues from year to year, and from age to age, unchanged. The air inclosed in jars, buried in Pompeii during 1800 years, was found to contain 21 volumes of oxygen in every hundred, as is now the case in every climate and at all seasons. Every cubic foot of oxygen extracted from the atmosphere by the above processes is immediately converted into a cubic foot of carbonic acid. And yet, notwithstanding these enormous

demands on the oxygen of the air, the average proportion of carbonic acid in the atmosphere is less than one-thousandth part of its weight, or one-tenth per cent. And is this apparently insignificant quantity sufficient for the supply of carbon to the whole vegetation of the earth's surface? This question is easily answered. It is known that a column of air of $14\frac{1}{2}$ lbs. weight rests upon every square inch of the surface of the earth; the diameter of the earth and its superficies are likewise known, so that the weight of the atmosphere can be easily calculated. The thousandth part of this is carbonic acid, which contains upwards of 27 per cent. carbon. By this calculation it can be shown that the atmosphere contains upwards of 3081 billion pounds of carbon—a quantity which, according to Liebig, amounts to more than the weight of all the plants, and of all the strata of mineral and brown coal existing on the earth. This carbon is therefore more than adequate to supply all the purposes for which it is required. The quantity of carbon contained in sea-water is proportionally still greater*.

* The successive steps in the calculation for ascertaining the quantity of carbon in the atmosphere may be thus briefly shown:—

		Log.
Log.	7900 miles or the earth's diameter	= 3·89763
„	1760 yards in 1 mile	= 3·24551
„	36 inches in 1 yard	= 1·55630
„	Diameter of the earth in inches	= 8·69944
		2
„	Square of ditto (= number of circular inches in a great circle of the earth) = ¼ of her surface	= 17·39888
„	3·1416 = No. of square inches in 4 circular inches.	= 0·49715
„	$14\frac{1}{2}$ the No. of lbs. of air on each square inch . .	= 1·16137
„	$\frac{1}{1500}$ the proportion of carbonic acid in the air . .	= 7·00000−10
„	$\frac{3}{11}$ the proportion of carbon in carbonic acid . .	= 9·43136−10
„	of the total quantity of carbon	35·48876−20

which is equal to 3,081,500,000,000,000 lbs.

Thus, by the removal of carbonic acid, and by the renewal of oxygen, plants maintain the atmosphere in a tolerably normal state, at least as regards its oxygen. Experience proves that the healthy state of a country is heightened by cultivation, and that the cessation of cultivation may render a healthy district uninhabitable. The experiments of De Saussure have shown that the upper strata of the air contain more carbonic acid than the lower which are in contact with plants, and that the quantity is greater by night than by day, as might be expected. In our winter, when vegetation is torpid, and carbonic acid is formed in excess in consequence of our method of producing artificial light and heat, our supply of oxygen is derived from the tropics and from warm climates, where vegetation is perennial, in exchange for which our excess of carbonic acid is conveyed by the winds to feed tropical vegetation.

This process will be better understood from the following considerations. The air within the tropics, being heated by the rays of a vertical sun, ascends with considerable force; to supply the vacuum thus produced, the cooler air of the temperate regions rushes in, forming a lower current charged with the accumulated carbonic acid, which the abundant vegetation of the tropics appropriates. Meanwhile the purer air of the tropics, which had ascended, forms an upper current, and proceeds in a contrary direction, namely, from the equator towards the poles, modified, however, by the earth's axial motion; but, as this upper current gradually parts with its heat by its exposure to space, it becomes cold enough at certain distances from the equator to descend and change places with the lower current. This it does usually at about 28° or 30°, where the trade winds cease, from which limit to lat. 60° in each hemisphere the prevailing winds at the earth's surface are from and

not towards the equator. In this way the carbonized air of the temperate zones is exchanged for the purer air of the tropics.

The beneficial action of plants upon the air admits of easy experimental proof. Sir Humphry Davy placed a turf, four inches square, in a porcelain dish, floating on the surface of water impregnated with carbonic acid gas. A glass vessel, of the capacity of 230 cubic inches, was made to cover the grass, to which water was occasionally supplied by a funnel furnished with a stop-cock. The water upon which the porcelain dish floated was daily supplied with fresh water saturated with carbonic acid, so that a small quantity of that gas must always have been present in the receiver. The volume of air in the receiver was found to increase by exposure to daylight; so much so, that, after the elapse of eight days, an increase of 30 cubic inches was observed. The air inside the receiver, on being analyzed, was found to contain 4 per cent. more oxygen than the air of the exterior atmosphere*.

That plants yield more oxygen to the atmosphere than they extract from it may also be proved from observations made on plants living under water. "Pools and ditches, the bottoms of which are covered with growing plants, often freeze upon their surface in winter, so that the water is completely excluded from the atmosphere by a clear stratum of ice; under such circumstances small bubbles of gas are observed to escape continually during the day from the points of the leaves and twigs. These bubbles are seen most distinctly when

* Every acre of land producing 10 cwts. of carbon gives annually to the atmosphere 2865 lbs., or 32,007 cubic feet, of free oxygen gas. An acre of meadow, wood, or cultivated land in general, replaces, therefore, in the atmosphere as much oxygen as is exhausted by 10 cwts. of carbon, either in its ordinary combustion in the air, or in the respiratory process of animals.—*Liebig*.

the rays of the sun fall upon the ice; they are very small at first, but collect under the ice and form larger bubbles. They consist of pure oxygen gas. Neither during the night, nor during the day, when the sun does not shine, are they observed to diminish in quantity. The source of this oxygen is the carbonic acid absorbed by the plants from the water, to which it is again supplied by the decay of vegetable substances contained in the soil. If these plants absorb oxygen during the night, it can be in no greater quantity than that which the surrounding water holds in solution; for the gas which has been exhaled is not again absorbed."

Dr. Daubeny's experiments on the action of plants upon the atmosphere (*Phil. Trans.*, 1836) may also be referred to. A plant inclosed in a large jar and supplied with carbonic acid was found to increase the quantity of oxygen in the jar from 21 to 26, 29, and even 30 per cent.; and this is probably a smaller increase than would have taken place in the open air, for, by introducing several plants into the same jar in succession at short intervals, the amount of oxygen has been raised from 21 to 39 per cent., and probably had not even then attained the limit to which the increase of this gas might have been brought. "How great, then, must be the effect of an entire tree in the open air under favourable circumstances! And we must recollect that the circumstances will be favourable to the vital energies of the plant, within certain limits at least, in proportion as animal respiration and animal putrefaction furnish to it a supply of carbonic acid."

II.—THE SOURCE OF HYDROGEN AND NITROGEN IN PLANTS.

We have thus traced the carbon of plants to its origin, and must next proceed to account for the other constituent elements. *All* the organs of plants contain carbon

and hydrogen; but the principal mass of every vegetable is composed of carbon and water, or, rather, the oxygen and the hydrogen are in the proportions to form water (viz. 1 part by weight of hydrogen + 8 parts by weight of oxygen). Thus woody fibre, starch, sugar, and gum are compounds of carbon with the elements of water. Most of the organic acids met with in plants consist of carbon, and oxygen, and hydrogen; but the proportion of oxygen is greater than would be required to form water with the hydrogen. A third class of vegetable compounds, such as the volatile and fixed oils, wax and the resins, consist of carbon and hydrogen with no oxygen, or with less than would form water with the hydrogen.

The hydrogen of plants is, therefore, derived from the decomposition of water in the sap. Bodies rich in hydrogen, such as wax, oil, and resin, must, for every one part by weight of hydrogen which they appropriate, give up to the atmosphere a quantity of oxygen equal to 8 parts by weight; or, in other words, for every pound of hydrogen assimilated by plants, above 100 cubic feet of oxygen are set free, so that the decomposition of water by plants is another most important means in the hands of Nature for purifying the atmosphere.

Nitrogen exists in a very small quantity in every plant, or in the juices which pervade it, and its origin has led to considerable discussion among Chemists. There is no good reason for supposing that the nitrogen of plants is derived directly from the atmosphere; on the contrary, many plants discharge the nitrogen which is absorbed by their roots, either in the gaseous form, or in solution in water: there is, however, a large amount of evidence in favour of the theory that the nitrogen of plants is conveyed to their roots in the state of ammonia derived from the decay of animal matter. This view was entertained long ago by De Saussure,

and has lately received the support of Liebig. "Ammonia," he says, "is capable of undergoing such a multitude of transformations when in contact with other bodies, that in this respect it is not inferior to water, which possesses the same property in an eminent degree. It possesses properties which we do not find in any other compound of nitrogen: when pure, it is extremely soluble in water; it forms soluble compounds with all the acids, and, when in contact with certain other substances, it completely resigns its character as an alkali, and is capable of assuming the most various and opposite forms. Formiate of ammonia changes, under the influence of a high temperature, into hydrocyanic acid and water, without the separation of any of its elements. Ammonia forms urea with cyanic acid, and a series of crystalline compounds with the volatile oils of mustard and bitter almonds. It changes into splendid blue or red colouring matters, when in contact with phloridzin, the bitter constituent of the bark of the root of the apple-tree; with orcin, the sweet principle of the *Lichen dealbatus;* or with erythrin, the tasteless matter of the *Roccella tinctoria.* All blue colouring matters capable of being reddened by acids, and all red colouring substances rendered blue by alkalis, contain nitrogen, but not in the form of a base."

The nitrogen of decaying animal matters, then, is discharged into the atmosphere in the form of ammonia, in the gaseous state in which it readily unites with carbonic acid to form a volatile salt, the carbonate of ammonia. Ammonia and its compounds being extremely soluble in water, every shower of rain must condense ammonia and convey it to the soil; consequently rain water must at all times contain ammonia; in larger quantity, however, in summer than in spring

or in winter, because in summer the intervals between the showers are longer, and the ammonia has time to accumulate. Still, however, the quantity of ammonia thus formed is so exceedingly small, that repeated analyses of atmospheric air have failed to detect it. If we suppose the air saturated with moisture at 59°, the whole of which is allowed to fall as rain, then one pound of rain water will be obtained from every 1132 cubic feet of air; all the ammonia contained in this quantity of air will also be returned to the earth in this pound of rain water. If there were only a single grain of ammonia in all this air, then undoubtedly the few cubic inches of air usually taken by the chemist for the purposes of analysis would contain only about 0·0000048 of a grain of ammonia, a quantity absolutely inappreciable by analysis; but, if a pound of rain water be examined, the ammonia becomes much more easy of detection, because this contains all the ammonia diffused through 1132 cubic feet of air. If a pound of rain water contain only one quarter of a grain of ammonia, then a field of 26,910 square feet must receive annually upwards of 80 lbs. of ammonia, or 65 lbs of nitrogen, a much larger quantity than is contained in the form of vegetable albumen and gluten in 2650 lbs. of wood, 2500 lbs. of hay, or 200 cwt. of beet root, which are the yearly produce of such a field; but it is less than the straw, roots, and grain of corn grown on the same surface would contain. Hence the necessity of supplying it to the latter crop in the form of manure.

The existence of ammonia in rain water was satisfactorily proved by Liebig. The rain water was collected 600 paces south-west of Giessen, when the wind was blowing in the direction of the town. When several hundred pounds of it were distilled in a copper still, and the first two or three pounds evaporated with the addi-

tion of a little muriatic acid, a very distinct crystallization of sal-ammoniac was obtained; but the crystals had always a brown or yellow colour. Similar crystals were obtained by evaporating several pounds of fresh snow in a vessel with muriatic acid. The ammonia obtained from these two sources had an offensive smell of putrefying matter, clearly indicating its origin.

The presence of ammonia in different parts of plants has also been abundantly proved. It has been found in the roots of beet, in the stem of the maple-tree and of the palm, and in all blossoms and fruit in an unripe state.

The value of ammonia as a manure will be considered hereafter; but it may be interesting to show how easily its presence may be detected in the fermenting matter of the dung heap. Sir Humphry Davy filled a large retort with hot fermenting litter and dung of cattle, and adapted a small receiver to the retort, and connected the whole with an apparatus for collecting the liquid and aeriform products. The receiver soon became lined with dew, and drops began, in a few hours, to trickle down its sides. In three days 35 cubic inches of gas were formed, consisting of 21 cubic inches of carbonic acid, the remainder being hydrocarbonate mixed with the nitrogen of the vessel. The fluid matter collected in the receiver amounted to about half an ounce; it had a saline taste and a disagreeable smell, and contained acetate and carbonate of ammonia.

Another retort filled with hot fermenting dung had its beak introduced into the soil among the roots of some grass in the border of a garden. In less than a week a very distinct effect was produced on the grass in that spot, which grew more luxuriantly than in any other part of the garden.

Another source of nitrogen in plants is nitric acid,

or aquafortis. Cavendish discovered in 1785, that, by passing a succession of electric sparks through a mixture of 7 volumes of oxygen and 3 of nitrogen, confined in a glass tube, nitric acid is formed. Now that which the electric spark does in such a mixture a flash of lightning accomplishes in the atmosphere, and nitric acid is formed, distinct traces of which are discoverable in the rain, which forms in thunder-storms, as was proved by Liebig in 1827. This distinguished chemist submitted seventy-seven samples of rain water, collected on different occasions, to the process of slow distillation. Of these samples, seventeen were collected during, or immediately after, thunder-storms. In the residue obtained from the seventeen, nitric acid was found in greater or less quantities in combination with lime or with ammonia. In fifty-eight of the other samples these nitrates were not found; and in the remaining two mere traces of nitric acid were just discoverable. The acid thus formed is washed down by rains into the soil, where it unites with potash, soda, and lime; these nitrates, being all soluble, are taken up by the roots of plants. Nitric acid is also generated in compost heaps, and generally where vegetable matter decays in contact with the air.

It will be seen from the foregoing details that carbonic acid, water, ammonia, and nitric acid contain some of the principal elements necessary for the support of vegetables, which, in their turn, furnish food to animals. "The same substances are the ultimate products of the chemical processes of decay and putrefaction. All the innumerable products of vitality resume, after death, the original form from which they sprung. Thus the destruction of an existing generation becomes the means for the production of a new one, and death becomes the source of life."—*Liebig.*

III.—ON VEGETABLE PRODUCTS—STARCH, FAT, GLUTEN.

It is now necessary to notice some of the principal substances produced in plants by the assimilation of their food.

If a handful of wheat flour be kneaded under a stream of water until the water ceases to be coloured, an elastic sticky substance will remain in the hand, and a white powder will subside in the water; the one is called GLUTEN, and the other STARCH.

STARCH is the representative of a group of substances consisting of carbon and water.

1. *Cellulose* or *woody fibre* forms the walls of the cells of plants, a considerable portion of the fibres of cotton and linen, wood, hay, straw, &c. It is insoluble in water, but in the form of fodder animals appear to digest it. It consists, by weight, of 36 parts of carbon, and 45 of water.

2. *Starch*, properly so called. Common starch contains 36 carbon and 45 water, but there are various starches in which the chemical composition is not exactly the same; thus, the flour of wheat, oats, barley, the potato, Iceland moss, lichens, the dahlia root, &c., furnish starches all more or less soluble in water.

3. *Gum.* By raising starch to the temperature of 300° gum is formed; as is also the case by digesting starch in dilute sulphuric acid. The gum thus formed is called *dextrine**, in which state it exists in the sap of plants. *Arabine*, or gum arabic, is soluble in cold water. *Cerasine*, or cherry-tree gum, is soluble in boiling water. These three varieties of gum have the same chemical composition as common starch.

* So called from its characteristic property of turning the plane of polarisation to the *right* when acting on polarised light.

4. The *mucilages*, or adhesive matter which water extracts from oily seeds, gum-tragacanth, &c. They consist of 48 carbon and 57 water.

5. *Sugar*. There are various kinds of sugar, as that from the sugar-cane, the maple-tree, the beet-root, from stalks of corn, and many other plants. It consists of 48 parts carbon and 66 water. In grapes and other fruits, and also in honey, is another kind of sugar called *grape-sugar*, consisting of 48 carbon and 84 water. It is not so sweet as cane-sugar, and it is not so soluble. It is formed artificially when cellulose or starch is boiled for a considerable time in water, acidulated with sulphuric acid.

6. *Pectine*. In the substances included in the five foregoing heads, the hydrogen and the oxygen are in the proportion to form water. There are certain vegetable substances resembling starch and gum, in which the hydrogen and oxygen are not exactly in this proportion. Thus, in fleshy fruits, such as the plum, peach, apricot, apple, pear, &c., and in the bulbs or roots of the turnip, carrot, parsnip, &c., there is no starch, but a substance called *pectine*, which answers the same purpose. It contains less hydrogen and more oxygen than starch.

A second group of substances, the FATTY GROUP, comprises the true fats and oils, waxes, turpentines, and resins. They all contain less oxygen than would be required to convert their hydrogen into water. The fats and fixed oils, vegetable as well as animal, are mixtures of two, and often three distinct compounds: the first of these is called *stearine* (from στέαρ, tallow or suet), and is solid at the temperature of the atmosphere; the second is *oleine* (from ἔλαιον, *oleum*, oil), and is liquid at ordinary temperatures, and even so low as 32°, the freezing point of water; the third substance is called *margarine*,

(from *μάργαρον*, a pearl), on account of its mother-of-pearl lustre; it forms the solid fatty ingredient of mutton-tallow, and is solid at ordinary temperatures. The fats are, therefore, mixtures of the fluid oleine with the solid stearine or margarine: if the solid be in larger proportion than the fluid, as in various kinds of tallow, it requires a greater degree of heat to melt it; if the fluid preponderates, as in the oils, the melting point is lowered.

By boiling wheat, oats, Indian corn, linseed, or even chopped hay and straw, in alcohol or ether, a portion of oil or fat, wax or resin, is separated.

Wax forms a coating to the flowers and leaves of many trees and shrubs, and it also forms the bloom on fruits. It is collected by bees; it is insoluble in water, but partly soluble in alcohol; it is almost tasteless, and very combustible.

The *turpentines* and *resins* abound in the pine tribe; they are insoluble in water, but soluble in alcohol; they are more combustible than fat or wax, and contain less oxygen than either.

We come now to notice the gluten, the sticky solid left behind after washing flour in a stream of water. Gluten is the representative of an important group of substances which contain *nitrogen* in addition to carbon, oxygen, and hydrogen.

1. *Gluten* is insoluble in water, but partly soluble in alcohol, which extracts from it a fatty oil; it dissolves readily in vinegar (acetic acid), or in solutions of caustic potash or soda. Wheat gluten also contains a substance called *glutine*, soluble in alcohol, and a kind of coagulated albumen, insoluble in alcohol.

2. *Albumen*, a vegetable substance resembling in its properties the albuminous portion or white of egg. It is soluble in water, but solidifies and becomes in-

soluble at a moderate heat. In the coagulated state it dissolves in vinegar, and in solutions of caustic, potash, and soda. When the juice or sap of plants is heated, the albumine coagulates and separates in opaque white flocks.

3. *Caseine* forms the curd, or solid part of milk when separated from the whey by means of rennet, or an acid. It may be obtained from oatmeal by shaking a portion up with cold water for about half an hour. On allowing the mixture to subside, and adding an acid to the clear liquid, a white powder separates, which has most of the properties of milk caseine. The meal of the bean, pea, &c., after being in contact with warm water, yields a substance closely resembling caseine on the addition of an acid. It may also be obtained from the sap of plants, and from the juice of the potato, turnip, and other roots, by first coagulating the albumen by heat, and then adding an acid.

Albumen, gluten, and caseine, and some other nitrogen compounds, such as *fibrine*, *emulsine*, and *legumine*, appear to owe their existence to a common base called *proteine**, which apparently derives its origin from the vital powers of plants, whence they are transmitted to animals as an essential part of their food. Proteine is composed of carbon, oxygen, and hydrogen, and about 16 per cent. of nitrogen; it also contains about 1 per cent. of sulphur.

The foregoing groups of substances must all exist in

* From πρωτεύω, to hold a chief place. Vegetable fibrine is the gray fibrous matter which remains after boiling the gluten of wheat in alcohol. Emulsine is contained in certain oleaginous seeds and kernels; it is considered by some chemists as identical with legumine, or the azotised principle of peas, beans, and similar seeds. Liebig regards legumine and caseine as one and the same principle.

those plants which furnish food to animals; if the plants are deficient in this respect, they become unfit food for animals, and it will be seen, as we proceed, that a deficiency in plants may arise from the absence of certain ingredients in the soil.

IV.—GERMINATION OF THE SEED.

It will be seen, from the examples given, that several substances ranging under the starch, fat, and gluten groups are contained in the seeds of plants. The seed is indeed a wonderful organism; it is the final result of vegetable life; a storehouse of nourishment for a new generation; the starting point of all husbandry; and Nature, with infinite care and foresight, has provided means for its preservation. In some cases it is surrounded by an abundant fleshy pulp, which supplies manure for its future development. In leguminous plants it is protected by a thick tough membrane, or it is covered with hard flexible scales, as in the gramineous plants, or incased in a hard woody substance, as in stone fruits. "Nature does not show herself less provident in furnishing means for scattering seeds and propagating vegetable species at great distances. There are, indeed, seeds which, furnished with light silky plumes, or wings, flutter in the air, and are transported afar by the winds. Others, by means of a viscous, hard, impermeable envelope, float on rivers, and descend their courses without suffering the slightest change, or losing their germinating power. There are seeds, again, of a sufficiently coherent texture to resist the digestive action of the stomachs of animals that feed on the fruits which contain them, and which are, consequently, often found deposited at great distances from the plant which produced them; they are thus frequently dropped to germinate and flourish at the tops of the

steepest mountains. By these admirable provisions of Nature, then, the air, the water, and even animals themselves, become the vehicles by which the migration of various vegetable species over the surface of the globe is effected."—*Boussingault.*

When the seed is gathered in the mature state, its vital functions are completely suspended, and it may often be kept for a very long time in this inert state without injury. The time, however, varies according to the species: the seeds of some plants preserve their germinative power for an indefinite period; others lose it very speedily, such as the seeds of the coffee plant, which must be sown almost as soon as gathered. Oily seeds are generally preserved with great difficulty; as also those of rubiaceous plants, of the laurels, myrtles, &c.

The farmer always does well to sow the most recent seed, even of the species which preserve their vitality longest. If often happens that after a short time a proportion of all seeds die; these have probably not been gathered under circumstances favourable to their complete preservation. Indeed it is known practically that, in sowing the seed-corn of former years, a much greater quantity is required than of recent seed*.

When the seed is committed to the earth at the proper season, it soon begins to sprout under the influence of warmth and moisture; a shoot is sent upwards, and a root downwards; but until the leaf expands, and the root has fairly taken possession of the soil, the young plant gets no nourishment, except water, either from the earth or from the air. It subsists on the starch and

* According to Humboldt, an aqueous solution of chlorine possesses the remarkable property of stimulating or favouring germination. Its action is so decided as to be apparent upon old seeds, which will not germinate under ordinary circumstances.

gluten, stored up in the seed: now these substances, as we have seen, are not soluble in water, though separable by it; hence they cannot be taken up by the vessels of the young plant, to which they furnish food, without undergoing some change. This change is very remarkable; at the base of the sprouting germ a portion of the insoluble gluten becomes converted into *diastase**, a white substance, which is not only soluble itself, but renders the starch soluble, so that the plant can assimilate it as it is wanted. The starch thus rendered soluble is called *dextrine*†. The dextrine thus formed from starch becomes changed into sugar, and this again into cellulose or woody fibre; and before the store of food contained in the seed is exhausted, the plant has already begun to live at the expense of the air and of the soil.

We have seen that the green parts of plants absorb carbonic acid from the air; retain the carbon and give back the oxygen; water abounds in the sap; and from these two sources, the carbon and the water, cellulose or woody fibre is formed. This substance may also be formed from the food taken in at the roots, from humic acid, for example, which also consists of carbon and water, as in woody fibre, only in different proportions. In like manner the starch of the seed may become changed into sugar, and this into cellular fibre, or the sugar may be transformed into starch; so skilfully does Nature elaborate substances of very different properties from the same materials, the only difference that we can detect being in the proportions employed.

In the process of malting, barley is steeped in cold water until it begins to sprout. It is then made into

* From διίστημι, *I separate.* It is the presence of diastase in malt that enables the sweet infusion (*sweet-wort*) to be formed.

† See note at page 70. In oily seeds which contain no starch, the place of dextrine is supplied by mucilage and oil.

a heap, or *couch*, upon the malt floor, when it absorbs oxygen and gives off carbonic acid: its temperature rises, and it is occasionally turned, to prevent its heating too rapidly. In this process the radicle lengthens, and the plumula, or *acrospire*, as the maltsters term it, elongates; and, when it has nearly reached the opposite extremity of the seed, its growth is stopped by drying, at a temperature raised slowly to 150° or more. The malt is then cleansed of the rootlets. The following analysis, by Dr. Thomson, of unmalted and malted barley will show the changes which take place in the operation:—

	Barley.	Malt.
Gum	5	14
Sugar	4	16
Gluten	3	1
Starch	88	69
	100	100

Thus it will be seen that, in the process of malting, the diastase which is formed makes the starch soluble in hot water; and, by further mashing in the wort, the dextrine is converted into sugar by means of the same diastase; a process similar to that of the growing plant. The insoluble gluten becomes soluble as diastase, by which means the insoluble starch is converted into soluble dextrine. The remaining part of the gluten ascends with the sap in some soluble form not well understood, and is supposed to assist in some way in the successive changes which are undergone by the starch, sugar, and gum of the sap.

In the growing shoot and root some compounds of nitrogen are present. In the young radicles of sprouting barley there are 32 per cent. of a substance containing nitrogen, while the grain contains only 14.

Nitrogen compounds seem to preside over the change of soluble substances in the sap into the insoluble fibre of the cells, and the change of the sugar and gum of the sap into the starch of the grain in the ear.

The leaves of the plants growing in sunshine exhale a portion of nitrogen, which is supposed to be derived from gluten and other proteine compounds; indeed, nitrogen seems to be necessary to plants in all stages of their existence, and hence one of the principal uses of manures. Nor is the nitrogen obtained altogether from ammonia and nitric acid. Animal substances containing nitrogen, made soluble by fermentation, probably enter by the roots, and thus contribute to the food of plants.

The function of annual plants is accomplished when they have stored up in their seeds in the form of vegetable albumen, starch, and gum, a quantity of nutriment adapted to the nourishment of a new race of plants. In perennial plants, such as shrubs, fruit, and forest trees, after their fruit or seed has been matured, the woody fibre which has been formed in spring becomes harder and more solid during the summer: but after August no more new wood is formed; carbonic acid continues to be absorbed, but it is used in forming a supply of nutritive matter for the following year. Instead of woody fibre, starch is formed and diffused through every part of the plant by the autumnal sap. From this starch, sugar and gum are elaborated in the following spring, which in their turn form the leaves and young sprouts. After potatoes have germinated, the starch contained in them is found to be diminished in quantity. When the buds, blossoms, and leaves of the maple tree are mature, the sap ceases to be saccharine. A willow branch contains a quantity of starch in every part of its woody substance, and puts forth

both roots and leaves in pure distilled or rain water; but as it grows the starch disappears, it being evidently exhausted in the formation of the roots and leaves. When the sugar-cane blossoms, part of the sugar disappears. Sugar does not accumulate in the beet-root until after the leaves are completely formed.

These well-authenticated observations remove every doubt, says Liebig, as to the functions performed by sugar, starch, and gum, in the development of plants, and explain why it is that these three substances exercise no influence on the growth or process of nutrition of a matured plant when applied to it as food.

V.—SALINE AND MINERAL CONSTITUENTS OF PLANTS.

It has been stated, that when a plant is burned its organic portion is destroyed, or escapes in a gaseous form, leaving behind an ash which differs in quantity and kind in different plants, and even in the same plant if grown on different soils. "Many writers," says Saussure, "consider that the mineral ingredients of plants are merely accidentally present, and are not at all necessary to their existence, because the quantity of such substances is exceedingly small. This opinion may be true as far as regards those matters which are not always found in plants of the same kind; but there is certainly no evidence of its truth with those invariably present. Their small quantity does not indicate their inutility. The phosphate of lime existing in the animal body does not amount to the fifth part of its weight, yet no one doubts that this salt is necessary for the formation of its bones. I have detected the same compound in the ashes of all plants submitted to examination, and we have no right to suppose that they could exist without it."

The mineral or inorganic portion of plants is derived from the soil, and consists of the *carbonates of potash, soda, lime,* and *magnesia*:—*silica,* which is the chemical name for pure flint, quartz, rock crystal, silicious sands, and sandstones:—*alumina,* or the pure earth of alum, which forms about two-fifths of the weight of porcelain and pipe clays, and other very stiff clays:—*oxide of iron,* the red oxide which imparts colour to red soils, and the black which colours many of the blue clays:—*oxide of manganese* exists in very small quantity in plants and soils:—*sulphur* is present in nearly all the parts of plants and animals*:—*sulphates,* such as those of potash, soda, ammonia, lime, magnesia, and oxide of iron:—*phosphoric acid* and the *phosphates* of potash, soda, ammonia, lime, and magnesia. Phosphate of lime is the principal constituent of bone, and exists largely in wheat, barley, and other grain:—*chlorides* of potassium, of sodium or common table salt, of calcium, and of magnesium, are also found in the ashes of plants.

It has been said that the quantity of ash yielded by different plants is unlike. For example, 1000 lbs. of the following substances in their ordinary state of dryness leave, on an average, the quantity of ash indicated:—

* Animal albumen, fibrine, and caseine contain sulphur, which distinguishes them from all other component parts of the animal body, and there is every reason to believe that the animal body derives these three important substances from plants. "Plants contain," says Liebig, "either deposited in their roots or seeds, or dissolved in their juices, variable quantities of compounds containing sulphur. In these, nitrogen is an invariable constituent. Two of the compounds containing sulphur exist in the seeds of cereal plants, and in those of leguminous vegetables, such as peas, lentils, and beans. A third is always present in the juices of all plants; and it is found in the greatest abundance in the juices of those which we use for the purpose of the table."

Wheat leaves about	20 lbs. of ash.		Wheat straw leaves about	50 lbs. of ash.	
Barley	30	„	Barley straw	50	„
Oats	40	„	Oat straw	60	„
Rye	20	„	Rye straw	40	„
Indian corn	15	„	Indian corn straw	50	„
Beans	30	„			
Peas	30	„	Pea straw	50	„

Meadow hay leaves from	50 to 100 lbs. of ash.	
Clover hay	90	„
Rye-grass hay	95	„
Potatoes	8 to 15	„
Turnips	5 to 8	„
Carrots	15 to 20	„

It may be concluded, from these tables, that, if the respective quantities of ash form an approximation to the respective amounts of inorganic food required for the growth of 1000 lbs. of each substance, a soil that yields a less quantity will suit those plants only to which a smaller supply is adapted. Thus trees which require only a small portion of mineral food may be grown on soils where arable crops would be starved. Thus the weight of ash left by 1000 lbs. of

Elm wood is	19 lbs.		Birch wood is	$3\frac{1}{2}$ lbs.	
Poplar „	20		Pine „	$1\frac{1}{2}$ to 3	
Willow „	$4\frac{1}{2}$		Oak „	2	
Beech „	$1\frac{1}{2}$ to 6		Ash „	5 to 6	

The quantity of inorganic matter varies in different parts of the same plant, as is evident from the amount furnished by the seed and the straw of the same plant. In a crop of corn, for example, a larger proportion of mineral matter is returned to the soil in the fermented straw than is taken away in the grain. The leaves of trees contain more inorganic matter than the branches, and the branches more than the stem, so that in autumn the leaves return to the soil a very large portion of the

soluble inorganic matters drawn up by the roots during the active season. The potato plant contains more potash before blossoming than after.

It was discovered by Professor Johnston, that the inorganic matter varies in different portions of the same *part* of the plant. Thus, the stalk of wheat, oat, or barley, being cut into four equal parts and burnt separately, the lowest portion gave the smallest amount of ash, and the highest portion the greatest.

The quantity of ash differs in different specimens and varieties of the same plant. Thus, wheat straw does not always yield the same quantity of ash, something depending on the variety of the plant, and something upon the nature of the soil. The degree of ripeness also has an influence, more ash being obtained from a plant fully ripe than from one in a less advanced state.

It might appear at first view that the quantity of inorganic food taken up by a plant was altogether accidental. Thus Saussure found magnesia in the ashes of a pine tree grown at Mont Breven, whilst it was absent from the ashes of a tree of the same species from Mont la Salle: the proportion of lime and potash was also very different. But Liebig has endeavoured to show that a plant, in whatever soil it grows, must contain an invariable quantity of alkaline bases. Culture alone will be able to cause a deviation. We must bear in mind that any one of many of the alkaline bases may be substituted for another, the action of all being the same*; so that a particular alkali may exist in one plant and be absent in another of the same species. Hence, the absent alkali or earth must be supplied by one similar in its mode of

* The reader will bear in mind that, although two different alkaline bases may act so much alike that one may be substituted for the other, such is not the case with the acids which accompany these bases. Sulphuric acid, for example, cannot be made to do the work of phosphoric.

action, or, in other words, by an equivalent of another base*. "The number of equivalents of these various bases which may be combined with the acid in a given plant must, consequently, be a constant quantity, and therefore the amount of oxygen contained in them must remain unchanged under all circumstances, and on whatever soil they grow." For example, in the above two cases given by Saussure, 100 parts of the ashes of the pine tree from Mont Breven contained—

Carbonate of Potash	3·60	Quantity of oxygen in the Potash	0·415
„ Lime	46·34	„ Lime	7·327
„ Magnesia	6·77	„ Magnesia	1·265
Sum of the carbonates	56·71	Sum of the oxygen in the bases	9·007

100 parts of the ashes of the pine from Mont la Salle contained—

Carbonate of Potash	7·36	Quantity of oxygen in the Potash	0·85
„ Lime	51·19	„ Lime	8·10
„ Magnesia	0·00		
Sum of the carbonates	58·55	Sum of the oxygen in the bases	8·95

The numbers 9·007 and 8·95 approached each other as nearly as could be expected, even in analyses made for the very purpose of ascertaining the fact above demonstrated; which the analyst in this case had not

* "Wiegmann and Polstorf planted several plants in a flower-pot filled with common earth from the garden, and watered them with weak solutions of chloride of potassium, and also of chloride of sodium, having previously ascertained that the earth contained mere traces of metallic chlorides. Subjected to this treatment, the plants flourished very luxuriantly, so much so that they completely covered the flower-pot, stretching far over its sides. They were then transplanted into the open soil, and no longer supplied with chlorides. In the following year they shrunk and died during the period of blossoming. It appears from these experiments that the plants required metallic chlorides for their proper nourishment, but that it is quite indifferent whether the chlorine be united with sodium or potassium."

in view. Liebig gives other cases supporting the same view, which seems to deserve further inquiry.

In estimating the ash with a view to practical agriculture, its quality must be considered as well as its quantity. The ash of one kind of plant may yield much lime, that of another much potash, that of a third much soda, that of a fourth much silica; or, in other words, one crop will carry off more of one mineral than another; one crop, such as wheat, will exhaust the soil more of some substances, and another crop, such as beans and potatoes, may exhaust it more of other substances, so that the land may suit one crop and not another. So, also, two successive crops of different kinds may grow where it would greatly injure the soil to grow two in succession of the same kind, and hence we get a natural reason for the "rotation of crops." The inorganic food carried off by one crop may be restored by other crops before the time arrives for the first crop to be grown again.

So, also, one soil may be favourable to the growth of one part of the plant and not to another part; the straw of corn may flourish and not the ear, for the straw contains comparatively little of some of the ingredients found in the ear; thus, the straw contains only a small portion of lime, magnesia, and phosphoric acid; the grain a large proportion of those substances. So, on the contrary, the straw contains much and the grain little silica; hence it will readily be seen that some soils will grow good straw with deficient ears, and others good ears with deficient straw.

The inorganic food of plants may appear trifling in a chemical analysis, but its amount is startling when we consider it in the crops carried off from an acre of land. The following case given by Professor Johnston will illustrate this in a striking manner. In a four

years' course of cropping, in which the crops gathered amounted per acre to—

1st year, *turnips* 20 tons of bulbs and $6\frac{1}{3}$ tons of tops.
2nd year, *barley*, 40 bushels of 63 lbs. each and one ton of straw.
3rd year, *clover* and *rye grass*, $1\frac{1}{2}$ ton of each in hay.
4th year, *wheat*, 25 bushels of 60 lbs. and $1\frac{3}{4}$ ton of straw.

The quantity of inorganic matter carried off in the four crops, supposing none of them to be eaten on the land, amounts to about

Potash	317 lbs.
Soda	54
Lime	193
Magnesia	55
Oxide of iron	15
Silica	356
Sulphuric acid	108
Phosphoric acid	116
Chlorine	70
Total	1284

or about 11 cwt.

Now if the entire produce be carried off and none of it restored in the shape of manure, it will be necessary, in order to restore the land to its original condition, to add to each acre every four years,

Dry pearl ash	465 lbs.
Common bone dust	552
Epsom salts	326
Common salt	116
Quick-lime	70
Total	1529

or more than $13\frac{1}{2}$ cwt.

The constant removal of such large quantities of

inorganic food must in time exhaust the soil and render it barren, unless restored by a judicious system of manuring. The soluble salts, such as those of potash and soda, are also liable to be washed out of the soil by rains. In general, land contains a good store of inorganic food, so that the deterioration is often a very slow process. "In the hands of successive generations a field may so imperceptibly become less valuable, that a century even may elapse before the change prove such as to make a sensible diminution in the valued rental. Such slow changes, however, have been seldom recorded; and hence the practical man is occasionally led to despise the clearest theoretical principles, because he has not happened to see them verified in his own limited experience, and to neglect, therefore, the suggestions and the wise precautions which these principles lay before him. General illustrations of this sure though slow decay, may be met with in the agricultural history of almost every country. In none, perhaps, are they more striking than in the older slave States of North America; Maryland, Virginia, and North Carolina,—once rich and fertile,—by a long-continued system of forced and exhausting culture, have become generally unproductive, and vast tracts have been abandoned to hopeless sterility*. Such lands it is possible to reclaim, but at what an expense of time, labour, manure, and skilful management! It is to be hoped that the newer States will not thus sacrifice their future power and prospects to present and temporary wealth, —that the fine lands of Kentucky, which now yield

* From every acre of this land were removed in the course of a century 12,000 lbs. of alkalis in leaves, grain, and straw; it became unfruitful, therefore, because it was deprived of every particle of alkali fit for the food of the crops, and because that which was rendered soluble, while the land was left fallow for a year, was not sufficient to satisfy the demands of the plants.—*Liebig.*

Indian corn and wheat, crop after crop, without intermission and without manure, will not be so cropped till their strength and substance is gone, but that a better conducted and more skilful husbandry will continue, without diminishing the present crops, to secure a permanent fertility to that naturally rich and productive country."—*Johnston.*

Another instance of exhaustion is alluded to by the same authority in the case of the West-India sugar plantations. The cane, after having had its saccharine juice pressed out at the mill, serves as fuel in boiling down the syrup. The ash thus produced is rich in those mineral ingredients necessary to the prosperity of the plant; and the neglect to return this valuable ash to the soil has not only occasioned a large importation of foreign manures, but also a serious deterioration of the soil.

VI.—THE COMPOSITION AND FORMATION OF SOILS.

It will be gathered, from the preceding details, that soils adapted to the growth of plants consist of two principal portions—the organic and the inorganic. The organic portion, or *humus*, as it is sometimes called (see page 58), consists of the decayed remains of animal and vegetable matter, and varies greatly in quantity in different soils. In peaty soils, it forms from 50 to 70 per cent. of the whole weight. In rich and long-cultivated soils, it has been known to amount to 25 per cent.; but, in general, the proportion is much smaller. Oats and rye will grow in a soil which contains only 1½ per cent. of humus; barley will flourish with only 2 to 3 per cent.; good wheat soils require from 4 to 8 per cent. In stiff clayey soils, from 10 to 12 per cent. have been found.

Now it must not be supposed that a soil is fertile in

proportion as it is rich in humus. Humus supplies plants with food in the form of carbonic acid by the roots; dissolved in water, humus acts injuriously; a very small quantity imparts to water a yellow or brown colour, a state in which manures cease to be beneficial to cultivated plants, because this colouring matter indicates a deficiency of oxygen to complete the conversion of the humus into carbonic acid. In a soil impregnated with this matter in solution, the roots of plants are deprived of oxygen, without which they cannot exist. For a similar reason the stagnant water of a marshy soil excludes air; but if the marsh be thoroughly drained, so as to admit the air freely, a fruitful meadow takes its place.

The inorganic portion of the soil consists of two subdivisions, the *soluble saline* portion from which the plant obtains nearly all the saline ingredients contained in the ash, and the *insoluble earthy* portion, which forms the great bulk of most soils, being rarely less than 95 lbs. in a hundred of their whole weight.

This earthy constituent consists of three main ingredients:—1, *Silica*, in the form of *sand;* 2, *Alumina*, mixed or combined with sand as *clay;* and, 3, *Lime*, in the form of carbonate, as chalk, limestone, &c. Soils are named according to the proportions in which these three ingredients are mingled together. According to Johnston, 100 grains of dry ordinary soil containing only 10 of clay would form a *sandy soil;* if it contained from 10 to 40 grains of clay, it would make a *sandy loam;* from 40 to 70, a *loamy soil;* from 70 to 85, a *clay loam;* from 85 to 95, a *strong clay* fit for making tiles and bricks; if it contain no sand, it would be pure agricultural clay, or pipe clay. With respect to alumina, it rarely happens that arable land contains more than from 30 to 35 per cent. of that substance. If a soil contain more than 5 per cent. of carbonate of

lime, it is called a *marl;* if more than 20 per cent., a *calcareous soil.* *Oxide of iron* forms 2 or 3 per cent. of sand soils, and in red soils much more.

The sand, lime, clay, oxide of iron, and organic matters mingled in various proportions, give rise to soils of various colours. In chalk districts the soil is white; in the coal fields the land is black; in the central part of England dark red soil prevails; in other districts the prevailing character of the soil is derived from yellow, white, and brown sands and clays.

The subsoil is of variable character; in some places consisting of porous sand or gravel; in others a light loam; in a third kind a stiff clay. On removing the soil we get to the solid rock, such as sandstone, limestone, slate-clay, &c. All kinds of rock by their disintegration will furnish either sandstone, limestone, or clays of different degrees of hardness, or a mixture of two or more of these in different proportions. By the action of winds, rain, and frost, rocks become disintegrated at the surface, seeds get deposited by some of the ingenious contrivances already noticed (page 74), and a soil slowly accumulates, partaking necessarily of the chemical character of the rock on which it rests. Thus, on a sandstone rock the soil is sandy; on a claystone it is, more or less, a stiff clay; on limestone it is, more or less, calcareous; and, if the rock be a mixture of these, a similar mixture will be observed in the soil formed by its crumbling. Geology has furnished the important observation, that, if the soil be bad on each of two contiguous rocks, it is generally of better quality at the place where the two rocks meet. Thus, where the plastic clay comes in contact with the top of the chalk, there is a much better soil than either on the clay or on the chalk; so also, where the chalk and the upper green sand mingle, there are fertile patches celebrated

for their wheat crops, in the production of which the phosphates in the marls are supposed to have an influence*.

The stratified rocks cover by far the largest portion of the earth, and form the principal bulk of various soils; these rocks are, doubtless, the ruins of more ancient strata or of unstratified masses; but even the unstratified rocks—the granites and the traps—contain a trace of most of the inorganic matter found in the ash of plants.

This soluble saline portion of the soils consists for the most part of *common salt* (chloride of sodium), *gypsum* (sulphate of lime), *Glauber's salts* (sulphate of soda), *Epsom salts* (sulphate of magnesia), with traces of the *chlorides of calcium, magnesium,* and *potassium;* the *nitrates of potash, soda,* and *lime;* these substances are also found in combination with *humic* and other organic acids.

It will, of course, be understood that these substances are not all found in the same soil. One soil may contain soda, and be deficient in the salts of lime; another may be well supplied with the phosphates, and be deficient in magnesia; and so on. Now, according as one or other of the above saline ingredients abounds, and others are deficient, so will the soil be favourable to certain plants and unfavourable to others. Thus, saline plants, which require common salt, seek the sea shore; but they are also found near the salt works of Germany, several hundred miles distant from the sea; their seeds have been carried by the wind or by birds, and spread over the whole surface, between the sea and the inland salt works; but these seeds germinate only in those

* Organic remains are in some places so abundant, as in the crag, that they are dug up as a natural source of phosphate of lime, usually supplied to the soil in the form of bones.

places where they find the conditions essential to the existence of the plants. Again, the chenopodium grows on the dunghill, where it finds the ammonia and the nitrates necessary to its existence, and it is attracted thereto just as the dung-fly is to animal excrement. So, also, the plants fitted for the food of man follow him, like the domestic animals, because the former find food, and the latter food and protection. The corn plants cannot thrive without a large supply of phosphate of magnesia and ammonia, which abound in soils where men and animals live together.

Although common salt abounds only in the vicinity of the sea, or of salt works, or beds of salt, yet it is distributed in small quantities, by natural processes, over a large extent of country. After storms at sea, the leaves of plants in the direction of the wind become covered with salt, to the distance of twenty or thirty miles inland. And, even in calm weather, the air hanging over the sea always contains a minute portion of this substance, which must be carried away by every breeze, and deposited on the soil with the rain. But sea water also contains the chlorides of potassium and magnesium, and the sulphates of soda and of lime, all of which must be conveyed by the winds to land in the vapour arising from the thousands of tons of sea water which are constantly evaporating into the atmosphere, and thus furnish plants with those salts which the soil would otherwise be incapable of yielding.

The saline ingredients of sea water thus raised by evaporation are exceedingly minute in quantity, and might be thought too insignificant to furnish any plants with their alkaline food; but, when we consider that a single grain of saline matter in every pound of a soil a foot deep is equal to 500 lbs. in every acre, we thus get a quantity of saline matter, more than is carried off

from the soil in ten rotations (forty years) supposing that only wheat and barley are sent to market, and that the straw and green crops are returned to the soil as manure. (Johnston.) So also, as Liebig remarks, the atmosphere contains only a thousandth part of its weight of carbonic acid; and yet, small as this proportion appears, it is quite sufficient to supply the whole of the present generation of living beings with carbon for thousands of years, even if it were not renewed. Sea water contains $\frac{1}{12400}$th of its weight of carbonate of lime; and this quantity, although scarcely appreciable in a pound, is the source from which myriads of marine mollusca and corals are supplied with materials for their habitations. Sea water contains less than a millionth of its own weight of iodine, which is collected by sea plants, just as alkalis are by land plants. Sea plants require metallic iodides for their growth, and land plants alkalis and alkaline earths.

Thus it will be seen that the evaporation of sea water will account for the presence of several saline substances in the soil. Others are derived from the decomposition of rocks, most of which, such as felspar, basalt, clay-slate, porphyry, and the numerous limestones, consist of compounds of silica with alumina, lime, potash, soda, iron, and protoxide of manganese.

The means by which rocks are disintegrated are partly mechanical and partly chemical. Water freezing within the pores or fissures of minerals acts like innumerable wedges, in separating the particles which fall asunder in the first thaw. Those who have visited the glaciers of Switzerland are struck with the wide-spread ruins of the mineral world, and have convincing proof of the enormous mechanical force of freezing water; but the glacier, in addition to this wedge-like action, has also a grinding action: during its slow but constant motion,

the masses of rock which have been thus separated from the sides, and form the lateral *moraines* between the icy stream and its rocky boundary walls, become crushed and reduced to powder, which, mingling with the innumerable rills set in motion by the heat of the sun, renders turbid the glacier stream, which forms the source of some of the most important rivers of Europe. This fluviatile deposit is very considerable, and in many situations, forms most valuable arable soil. "As often as I have seen beds of mud, sand, and shingle, accumulated to the thickness of many thousand feet, I have felt inclined to exclaim, that causes such as the present rivers and the present beaches, could never have ground down such masses. But, on the other hand, when listening to the rattling noise of these torrents, and calling to mind that whole races of animals have passed away from the surface of the globe during the period throughout which, night and day, these stones have gone rattling onwards in their course, I have thought to myself, Can any mountains, any continent, withstand such waste?"—*Darwin.*

The chemical means adopted by Nature for the disintegration of rocks may be illustrated by one or two examples. Those minerals which contain metallic sulphurets become, by the gradual absorption of oxygen, converted into sulphates, which are not only soluble in water, but absorb moisture from the air and thus crumble down. In the disintegration of silicious minerals, the process is equally simple, but requires a little more explanation. Silica, a very pure variety of which occurs in *quartz,* is insoluble both in hot and cold water; it unites with alkalis, and forms saline compounds termed *silicates;* the silicates of potash, soda, and lime are neutral compounds; and, as this property of neutralizing metallic oxides and alkalis belongs only to acids, silica has obtained the name of *silicic*

acid. This acid, as may be supposed, is exceedingly feeble, so much so, that soluble silicates can be decomposed even by carbonic acid. *Felspar*, one of the ingredients of granite*, may be regarded as a silicate of alumina with silicate of potash, the last of which being gradually removed by water, forms the celebrated *kaoline* or porcelain clay. Water containing carbonic acid also makes a sensible impression on quartz. In an experiment quoted by Liebig, some white sand was thoroughly cleansed by boiling in nitro-muriatic acid, and after completely removing the acid by washing the sand with water, the sand thus purified was exposed to the action of water saturated with carbonic acid. After the lapse of thirty days this water was analyzed, and found to contain in solution silica, carbonate of potash, lime, and magnesia; thus proving that the silicates contained in the sand were unable to withstand the continued action of water containing carbonic acid, although the same silicates had resisted the short action of aqua regia. So also, in nature, felspar, and all minerals and rocks containing silicates of alkaline bases, cannot resist the continued solvent action of carbonic acid dissolved in water; and in this way, either in the form of soluble silicates or a hydrate of silica, this important ingredient in some plants is taken up by the roots. All plants of the grass kind require silicate of potash, the amount of which removed from a meadow in the form of hay is considerable, as will be evident to any one who examines the melted ashes of a haystack which has been consumed by fire.

* The other two ingredients are *quartz* and *mica*. A single cubic foot of felspar, according to Liebig, is sufficient to supply an oak copse covering a surface of 26,910 square feet with the potash required for five years.

VII.—ON MANURES.

The seeds of beans, peas, garden cress, &c., will germinate and even grow, to a certain extent, in moist sand or moistened horsehair. In such case, the only mineral substance is that contained in the seed, and when that is exhausted the plant dies; it may blossom, but it can never bear seed, because some of the principal ingredients of the seed are absent.

Various plants were grown in the purified sand described at page 94. Barley and oats grown in this way, and moistened with pure water, reached a height of 18 inches; they blossomed, but did not come to seed, and died soon after. Vetches reached a height of 10 inches, blossomed, and put out pods, but they did not contain any seeds. Tobacco attained the height of only 5 inches in four months; the plants had only four leaves, and no stem. The analysis of the ashes of these plants proved that the sterile sand had yielded a certain small amount of potash and soluble constituents, on which the growth of the leaves and stems depended; phosphoric acid was also detected, but its quantity proved it to have been derived from the seeds sown. By an instructive variation of these experiments, an artificial soil was prepared from the same sand, with salts prepared in the laboratory. Seeds of the same plants were sowed in this soil, and they flourished in the most luxuriant manner. The tobacco rose to the height of three feet, put forth many leaves, blossomed, and ripened its seed. So also barley, oats, buck-wheat, and clover grew luxuriantly, blossomed, and yielded ripe and perfect seeds*.

The growth of these plants, doubtless, depended on the addition of the salts to the sterile sand. In the same

* Wiegmann and Polstorf's Prize Essay, quoted by Liebig.

manner any other plant might be made to grow in a similar artificial soil, provided those saline and mineral substances were added to it which analysis proves must exist in the stem, leaves, and seeds of the matured plant. The ashes of the same plants, though grown on different soils, very closely resemble each other in chemical composition. Silica and potash are always present in the straw of the Gramineæ; and in their seeds there is always phosphate of potash and phosphate of magnesia. In the straw of peas and in clover a large quantity of lime occurs. Liebig classifies cultivated plants according to the solubility of their ashes, into—1, *Potash plants*, the ashes of which contain more than half their weight of salts with alkaline bases (potash and soda), soluble in cold water; 2, *Lime plants*, the ingredients of which are salts of lime and magnesia, soluble in acids; 3, *Silica plants*, in which silica predominates, and this is insoluble in acids. Potash plants include the chenopodia, arrach, wormwood, &c., and, amongst cultivated plants, the beet, mangelwurzel, turnip, and maize. Lime plants include the lichens (which contain oxalate of lime), the cactus (which contains crystallized tartrate of lime), clover, beans, peas, and tobacco. Silica plants include wheat, oats, rye, and barley. In our cultivated plants, soda appears in some cases to be substituted for potash, but it does not appear that lime can replace the alkalis in these plants.

The art of manuring land depends chiefly upon two considerations: first, a knowledge of the inorganic constituents of the crop intended to be grown; and, secondly, a knowledge of the constituents of the soil, or, in other words, the soil must be able to supply the crop with mineral food, sufficient in kind and quantity to enable it to arrive at maturity. For example, in

preparing the soil for potatoes, the farmer ought to know that both lime and potash are required; for the potato plant belongs to the lime plants as regards its leaves, and to the potash class as respects its tubers. So also, in growing beet-root, phosphate of magnesia is required, and only a small quantity of lime; but in growing turnips much phosphate of lime is required, and only a small quantity of magnesia.

It has been already shown how a soil may be rendered perfectly sterile even for weeds, by carrying off crops every year, and returning nothing to the soil in the shape of manure. This state of sterility may be produced sooner by one plant than another. If, for example, the soil be poor in phosphates, but rich in silicates, wheat will exhaust it sooner than oats or barley, because a larger amount of phosphates is removed in the seeds and straw of one crop of wheat, than in three or four crops of barley or oats. If the soil be deficient in lime, barley will not flourish. However rich the soil may be in silicates, seed cannot be formed without phosphates; we may grow admirable straw for Tuscan bonnets, but we shall get little or no bread.

When the supply of phosphates in a soil is limited, while alkaline silicates are abundant, the exhaustion of the phosphates may be delayed by a judicious system of rotation of crops; if, for example, we alternate, with the wheat, plants which are usually cut before they come to seed; or plants which require scarcely any phosphates. If peas and beans be cultivated on this soil, they will leave in the soil, after the crop is removed, a quantity of silica in a fit state to feed a succeeding crop of wheat, but they will rob the soil of phosphates quite as much as the wheat. The exhaustion of the phosphates may, however, be delayed by adopting a

rotation in which potatoes or clover are made to alternate with a white crop, the former crops being rich in sugar, starch, &c., but containing little phosphate.

The large amount of phosphates which are carried off by our crops and by grazing animals are for the most part returned back to the soil in the form of bone manure, a single pound weight of which contains as much phosphoric acid as a whole hundredweight of corn. In this way, while our farmers are paying large sums of money to foreign countries for bone manure, our domestic arrangements are so faulty that we waste every year thousands of hundredweights of phosphates in the form of urine and solid excrements, which are allowed to flow out into the sea by the Thames and other rivers.

A field properly prepared for culture ought to contain in sufficient quantity, and in a form adapted for assimilation, all the inorganic materials required by plants. It must also contain a certain amount of ammoniacal salts and decaying vegetable matter. In such a field the system of rotation is, that a potash plant (turnips or potatoes) is succeeded by a silica plant, and the latter is followed by a lime plant (peas or clover). The potash plant requires alkalis, and only a small quantity of phosphates; the silica plants require, in addition to the soluble silica left by the potash plants, a considerable quantity of phosphates; and the lime plants may take away so much of phosphates, that only enough may be left to grow a crop of oats or rye. Thus, the soil may suffice for two successive crops of a potash or of a lime plant, and for three or four crops of a silica plant; after which, the mineral substances removed from the field in the form of fruit, herbs, or straw, must be restored in the form of manure, or the land will lose its fertility.

The richest and most valuable manure is to be found in the excrements of animals. A man or an animal consumes daily in the shape of food a certain quantity of carbon, hydrogen, oxygen, nitrogen, and sulphur, as also a considerable quantity of mineral ingredients, identical with those which we have been considering as the ashes of plants. In a full-grown man the food thus consumed amounts in the course of a year to a much greater weight than that of his own body; in addition to this he requires an aerial aliment, without which he could not exist. In the process of respiration a quantity of oxygen combines with the blood, amounting at each respiration to about two cubic inches, and, in twenty-four hours, to from 20 to 25 ounces. But, although we take into our bodies pounds' weight of food, and pounds' weight of oxygen, the weight of the body continues stationary, or nearly so; we take in with our food a quantity of alkalis and phosphates, and yet the amount of these substances in the body is not increased.

Now the oxygen and the food thus taken into the body exert a mutual action on each other; a sort of slow combustion is maintained, the results of which are the same as in the burning of carbon and of hydrogen by fire; the oxygen and the carbon unite to form carbonic acid, and the oxygen and the hydrogen unite to form water. Thus, the carbon and hydrogen of the food are expelled by the lungs and through the skin, in the form of carbonic acid and vapour of water; the nitrogen of the food is collected in the urinary bladder, in the form of *urea*, which, by uniting with the elements of water, forms carbonate of ammonia. The soluble mineral constituents of the food are also contained in the urine, while the insoluble ingredients are contained in the fæces. Thus all the constituents of the food are expelled

in the full-grown man; in the growing animal and in the process of fattening, where an increase of weight takes place, part of the constituents of the food remain in the body; in old age the weight of the body decreases, so that more matter leaves the body than enters it. By these wonderful chemical processes vitality is sustained and animal heat generated.

If we trace the history of a crop taken from a field, it will be found that a portion is used in feeding and fattening animals, or, in other words, a portion of the crop is transmuted into beef and mutton, which are consumed by man. Another part of the same crop may be consumed in the form of potatoes, meal, or vegetables; while a third part, consisting of the remnants of plants, may be employed as litter in the form of straw, &c. The constituents of the field, thus removed in the form of animals, corn, and fruit, may evidently be again obtained in the liquid and solid excrements of man, in the bones and blood of the slaughtered animals, and in the litter of the dung heap. It depends upon the farmer to keep his land in a constant state of composition and fertility by carefully collecting these substances. How much of the ingredients of the soil are removed by a sheep, by an ox, or in the milk of a cow, can be calculated, or how much is conveyed from it in a bushel of barley, wheat, or potatoes. From the known composition of the excrements of man, it can also be calculated how much of them it is necessary to supply to a field to compensate for the loss that it has sustained by the renewal of a crop.

In every system of manuring it is not the *name* of the manure, but its chemical composition, that constitutes its agricultural importance. It is of course unimportant whether we obtain ammonia in the form of urine, or from the ammoniacal liquor of the gas house;

or whether phosphate of lime be in the form of bones, or the mineral apatite. The chief object of manure is to restore to the land the substances which animals and crops have taken away from it, and which cannot be restored by the atmosphere.

It will thus be seen that manures may be drawn from all three kingdoms of nature. Vegetable manure loosens the land by opening its pores, and by admitting air reduces the organic food, and saline and earthy matters, to the state in which the roots can imbibe them. But the quantity and kind of vegetable manure are of importance, so as to not overload the soil. For example, a thousand pounds' weight of willow sawdust, fermented and added to the soil, impart only 4½ lbs. of saline and earthy matter, while the same quantity of dry willow leaves will contribute 82 lbs. of inorganic food. *Green manuring*, as it is called, or sowing a crop, such as rye, buckwheat, wild mustard, &c., and ploughing it into the soil while green, is a useful practice: the juices of the plant soon begin to ferment, and the vegetable matter is thus more equally diffused through the soil, and by this natural decay of vegetable matter ammonia and nitric acid are produced for the succeeding crop. If the farmer were to collect the green sods and weeds of his lanes and fences into compost heaps, he would always have a supply of valuable manure*. Sea-weed is an excellent green manure; it decomposes easily, and yields organic food and saline matters of great value.

Dry vegetable manure, such as *straw*, ought to be

* As the principal action of animal excrements depends upon their amount of mineral food, it follows that we might manure with the mineral food of wild plants, that is, with their ashes; for these plants are governed by the same laws in their nutrition and growth as cultivated plants themselves. Thus, by a proper use of the ashes of wild plants, we might return to our fields the constituents removed from them by crops of cultivated plants.—*Liebig.*

mixed with urine and the droppings of cattle, so that by its fermentation its particles may be brought into that state of minute subdivision in which alone it can form the food of plants. *Sawdust*, saturated with the ammoniacal liquor of the gas works, or with liquid manure, is good for raising turnips. Sawdust may be charred by burning, or by mixing with quick lime. *Bran* and *pollard* of wheat, moistened with urine and slightly fermented, form a good manure. *Brewers' grains* mixed with farmyard manure; *malt dust*, or the dried sprouts of barley, formed in the process of malting, are also useful. The seeds of plants are more enriching to the soil than the substance of their leaves and stems; thus *rape seed*, after the oil has been expressed, is good for land, especially when used with other manure. *Charcoal powder* absorbs noxious vapours from the air and the soil; it also absorbs oxygen and other gases; hence it forms a valuable mixture with liquid manure, night soil, farm-yard manure, ammoniacal liquor, and other rich manures. Seeds sown in moistened charcoal sprout with remarkable quickness and certainty. *Soot* contains from 18 to 48 per cent. of mineral matters, consisting of earthy substances from the coal, and of gypsum and sulphate of magnesia derived from the lime of the flue and the sulphur of the coal. It also contains from 1 to 5 per cent. of ammonia, chiefly sulphate. Hence it is a most valuable manure. It must, however, be used with caution, because, when applied to grass in the spring, it is said to give a bitterness to the pasture, and even to communicate that taste to the milk. *Coal dust*, or that which is too small for burning, is used in arable land, or as a top dressing upon old pastures. *Coal tar* may be used in the form of a compost, or applied to wheat stubble by means of the water cart, and allowed to remain two or three

months before being ploughed in. *Peat* contains a valuable store of organic matter, capable of improving the adjacent soils. By draining off the sour and unwholesome water, and applying lime and clay, peat bogs may be converted into rich corn-bearing lands. *Tanner's bark* may also be used when it can be got easily and cheaply—a remark which apples equally to almost every form of manure.

Vegetable manures are valuable according to the relative quantity and kind of inorganic matter contained in them, and also by their relative proportions of nitrogen. The immediate effect of such manures depends on their nitrogen; their more permanent effect on the quantity and quality of inorganic matter.

Animal manures which contain much water, such as flesh and blood, decay rapidly, and are fitted to operate immediately on vegetation; but their action is temporary. Dry animal manure, such as bone, decomposes more slowly, but the beneficial effect remains through several seasons. *Flesh* is rarely used as a manure, except in the case of horses or cattle dead from disease. *Fish* is in some districts employed extensively as a manure, such as the refuse of the herring and pilchard fisheries, sprats, herrings, dog fish, and mackerel when very abundant. It should be made into a compost with a large quantity of soil. *Shell fish* is a valuable manure, especially if crushed. *Blood* makes an excellent compost with peat ashes and charcoal powder. *Animalized charcoal* is blood from the sugar refineries, in which lime water and bone charcoal have been employed in refining the sugar. It contains about 20 per cent. of blood, and is so much esteemed in France, that the sugar refiners sell it for more than the unmixed blood and animal charcoal originally cost them. This has led to a spurious imitation, which is much less efficacious than the original. The *parings of skins* from the tan works are

first boiled down by the glue makers, and the insoluble refuse sold as manure. *Horns, horn sawdust, hoof-parings, hair*, and *wool* are all valuable and permanent manures. Blood and flesh contain from 80 to 90 per cent. of their weight of water; but a ton of horn shavings, of hair, or of dry woollen rags is as efficacious as 10 tons of blood; but, as they decompose more slowly, they *appear* to be less effectual than blood. *Bones* form a very valuable manure. 100 lbs. of bone dust convey to the soil as much organic matter as 33 lbs. of horn, or 300 or 400 lbs. of blood or flesh; they also add about two-thirds of their weight of inorganic matter, consisting of lime, magnesia, soda, common salt, and phosphoric acid, all of which must be present in a fertile soil. In order that bones may be the more readily available as food for plants, the bone dust is mixed with dilute sulphuric acid, which completely dissolves it in two or three days. The solution or paste may be dried up with charcoal powder, dried peat, sawdust, or fine vegetable soil, and applied with the drill to the turnip crop, or diluted with fifty times its bulk of water, and applied with the water cart.

But it is in the solid and liquid excrements of an animal that manure obtains its highest value, especially for those plants which furnished food to the animal. The dung of pigs fed upon peas and potatoes is best adapted to manure a field growing peas and potatoes. In feeding a cow upon hay and turnips we get a manure containing all the mineral constituents of grass and of turnips. The dung of pigeons contains the mineral ingredient of the cereal grains; that of the rabbit the constituents of culinary vegetables; the solid and liquid excrements of man contain in very great quantity the mineral substances of all seeds.

A thousand pounds of urine contain 68 lbs. of dry

fertilizing matter of the richest quality, worth at least 10*s.* per cwt. at the present rate of selling artificial manures in this country. Each full-grown man voids about 1000 lbs. of urine in a year, which is equal in value to about 6*s.* per head. The urine of two men is said to contain sufficient mineral food for an acre of land, and mixed with ashes will produce a fair crop of turnips. In Flanders, where much manure is used, the collected excrements of a man for one year are valued at 27*s.* In Belgium the value is still higher. "At Bruges," says Mr. Chadwick, "I found that it (the night soil) is considered a very valuable perquisite. I was told a housemaid of all work might be got for 3*l.* a year wages and the night soil." One hundred parts of wheat grown on a soil manured with cow dung (which contains only a small proportion of nitrogen) afforded only 11·95 parts of gluten, and 62·34 parts of amyline or starch; whilst the same quantity grown on a soil manured with human urine yielded the maximum of gluten, namely, 35·1 per cent., or nearly three times the quantity. Human urine has a greater manuring value than that of the cow, horse, and sheep. Its salts contain above 8 per cent. of phosphates, which are entirely absent in the urine of other animals, except that of the pig, which contains phosphoric acid.

The liquid manure of a farm should be collected in well-covered tanks, puddled with clay, to prevent the loss or escape of the liquid. Each tank should be divided by a wall into two compartments, capable of holding each two or three months' supply. When the first is full, the stream should be turned into the second, and by the time this is full the first is ripe and fit for the land: it ought always to be applied in a fermenting state. The fresh urine of cattle, &c., ought to be mixed with its own bulk of water; by which means the loss of

ammonia is prevented, as also the caustic effects of urine on the land. Sulphuric acid may also be added to fix the ammonia.

Burnt gypsum mixed with urine forms a manure called *urate* by the dealers; but it is much better to fix the ammonia by means of sulphuric acid, and evaporate the whole to dryness. The dry powder thus obtained is sold as a manure, under the name of *sulphated urine.* It contains all the saline substances of liquid urine, and is a most valuable manure.

Night soil differs in value according to the food of the animals which produce it: it is rich in proportion to the amount of animal food consumed. It is formed into various composts by mixing with gypsum, wood charcoal, sawdust, vegetable soil, &c. In France it is dried first in the air, and then in stoves, and sold under the name of *poudrette.* It is said to be equal in effect to thirty times its bulk of horse or street manure.

It is only within the last year or two that attempts have been made to collect and apply to useful purposes the enormous quantities of valuable liquid manure discharged into the Thames from our common sewers. The evidence laid before the Health of Towns' Commission, and the Select Committee of the House of Commons, previous to the granting of an Act to the "Metropolitan Sewage Manure Company," furnishes much curious and useful information. Thus, in the evidence of Professor Miller, of King's College, it appears that the sewer named the *King's Scholar's Pond* discharges, on an average, about thirty gallons of liquid per second, or about two millions and a half gallons daily. In this daily flux of liquid about a ton weight of potash is lost, and about the same quantity of the phosphates of the earths; that is, about a ton of phosphoric acid, in combination with lime and magnesia,

is emptied from this sewer every day in waste. To this stupendous loss must be added from one to two tons of ammonia.

The money value of the salts thus thrown away is very considerable. The salt of ammonia is worth at least 16*s.* per cwt. Now one ton of ammonia is equal to three tons of any salt of ammonia, which would give a daily loss of 48*l.* in ammonia only, and from only one sewer. "In the same way," says Professor Miller, "about a ton of earthy phosphates, or bone earth, the commercial value of which is not less than 3*l.* a ton; say the same for the potash thrown off; we shall have 54*l.* worth passing off every day, actual money value. The quantity of solid matter in suspension—say it amounts even to double the quantity I have found (I found nearly 50 grains per gallon), say 100 grains, would yield daily about sixteen tons (of course taking for granted that the calculation for the delivery of this sewer is correct); it would yield daily sixteen tons of solid matter in suspension, which at 10*s.* per ton would be worth only 8*l.*; so that we have for the liquid manure an excess of value of 46*l.* over the solid.

"The daily loss is 54*l.* for the liquid; and the total loss would be about 64*l.*"

Occupiers of land on the continent have, for many years, been aware of the eminent advantages of liquid manure. So long ago as 1829, when Mr. Harley published an account of the various methods of dairy husbandry pursued by the Dutch, the practical application and advantages of liquid manure were well understood by that industrious and intelligent people. The method adopted was as follows:—Early in the season, part of the proprietor's farm, and some small fields near the cowhouse, were sown with barley and grass seeds, and watered with dilute cow urine, by means of a fire engine.

Barrels full of urine were also conveyed to the land on hand barrows with broad wheels, which were easily wheeled along the rich soft ground, which would have been destroyed by horses and carts. The contents of the barrels were discharged by means of pipes about eight feet long, perforated with small holes. The grass of the field thus irrigated was cut five or six times a year; and, though not very long in the blade, there was always great weight of produce. Indeed, it was so thick and rich, that it would have rotted unless cut often. The first cutting generally commenced about the middle of April, and was continued once a month. The grass was cut during the day when the weather was wet or moist; but, when it was dry, it was cut late at night, or early in the morning, and the field irrigated immediately after being cut.

In this, as in several other cases, the cows, sheep, and horses prefer the grass irrigated with night soil to any other. In an experiment made by Dr. Guy, in which the grass of a park had been partly irrigated with sewage, the animals found the irrigated grass so grateful to them, that, "while in other parts of the park they have suffered the grass to grow without let or hindrance, they here keep it close nibbled, and will not give it an opportunity of growing."

It is satisfactory to find that British farmers are *beginning* to appreciate the value of liquid manure. The evidence of several practical men as to its advantages are peculiarly interesting. Thus Mr. Dickinson, of Willesden, says:—"They (the oats and tares) were so wonderful after the grass, that I took them as samples to the agricultural show at Beverley; and the Yorkshiremen were astonished beyond measure at the grass report. Their argument was this—'You have exhausted your soil.' I said, 'I was aware that you would say

so, and therefore I have brought the plants of the tares and the oats.' The number of grains was astounding, so that there must have been in the earth the remains of the power of this urine used to the grass before." Mr. Chadwick relates the experience of Mr. Barber, Muirdroachwood. This gentleman had twenty-seven acres of land before his house, so poor that it originally fed only two cows. In a stable near the house were forty cows and four horses. The dung of the cows was put into a tank and largely diluted with water, and with this he irrigated twenty-two acres. With the refuse of his house and scullery he irrigated five acres. The produce was so large, that on that same plot he has been enabled to feed all the cows and the horses; that is to say, the increased produce was such, that forty-four animals were fed where there had previously been only enough food for two. Mr. Smith, of Deanston, says—" the practical result of this application of sewer water is, that land which let formerly at from 40*s.* to 6*l.* per Scotch acre, is now let annually at from 30*l.* to 40*l.*, and that poor sandy land on the sea shore, which might be worth 2*s.* 6*d.* per acre, lets at an annual rent of from 15*l.* to 20*l.* That which is nearest the city brings the higher rent, chiefly because it is near, and more accessible to the points where the grass is consumed, but also partly from the better natural quality of the land. The average value of the land, irrespective of the sewer water application, may be taken at 3*l.* per imperial acre, and the average rent of the irrigated land at 30*l.*, making a difference of 27*l.*; but 2*l.* may be deducted as the cost of management, leaving 25*l.* per acre of clear annual income due to the sewer water."

Liquid manure is admirably adapted to the wants of garden produce generally, and, in order to supply it in

unlimited abundance to the numerous market gardens situated to the west of London, the Metropolitan Sewage Manure Company have erected works at Fulham, where, by means of a large main pipe, they receive the liquid manure from one of the largest London sewers. From this main pipe smaller pipes branch off to the gardens, from which the gardener can draw off an unlimited supply of liquid manure properly prepared and in the finest condition for directly supplying food to the plants.

The manure of various animals differs greatly in quality. Some varieties, such as those of the cow and pig, are called *cold*, because they do not ferment readily; the horse, taking less liquid food and discharging less urine, yields a richer dung. The dung of nearly all birds has valuable fertilizing properties; it possesses the united virtues of liquid and solid manure; inasmuch as it contains every part of the food of the bird, and thus returns to the plant a greater number of those substances on which plants live, than either of the solid or the liquid excrement of other animals. Guano has of late years become celebrated: it is the dung of sea fowl, and contains a large quantity of ammonia and of phosphates, and most of those substances on which plants subsist: it is, however, deficient in potash, so that in its application wood ashes make a useful addition. Its high price has led to much adulteration, and even to the manufacture of an article called "guano," in which Professor Johnston was unable to detect a particle of that substance: gypsum and umber are the chief adulterants of guano.

It will be seen, from the foregoing details, that the chief object of vegetable and animal manures is to furnish the growing plant with food such as it can digest; with ammonia and carbonic acid, with saline and mineral ingredients. We have seen that it is a

matter of indifference whether the substances which have been removed from the soil by one crop be restored to it in the form of excrements, ashes, or bones. "A time will come," says Liebig, "when plants growing upon a field will be supplied with their appropriate manures prepared in chemical manufactories—when a plant will receive only such substances as actually serve it for food, just as at present a few grains of quinine are given to a patient afflicted with fever, instead of the ounce of wood [Peruvian bark] which he was formerly compelled to swallow in addition." The chief point for consideration will be whether the chemical manufacturer can supply saline and mineral manures—ammoniacal salts, the salts of potash, and soda, &c.—as cheaply as the intelligent farmer can prepare or procure them from the materials of his farm and homestead, and from the sewage of towns; for there cannot be a doubt that before long we shall not be sending whole fleets of merchant vessels to distant parts of the world for bones and guano while we actually allow to flow out to waste, from the London sewers into the Thames, salts of the annual value of 433,879*l.* sterling! "The importation of urine or of solid excrements from a foreign land," says Liebig, "is quite equivalent to the importation of corn and cattle. All these matters, in a certain time, assume the form of corn, flesh, and bones; they pass into the bodies of men, and again assume the same form which they originally possessed." This striking remark cannot fail to be appreciated in the course of time, when instead of polluting our noble rivers, destroying the fish, and breeding pestilence in our towns, the contents of our sewers will be transferred to the land, exalting the fertility of that which is now under culture, and redeeming that which has hitherto been considered as hopelessly sterile.

The subject of chemistry, whether pure or applied, has claims upon the attention of all classes of readers; nor are its intellectual claims alone paramount, for it is the duty of every thoughtful person to study the sources of national prosperity, and to understand the secrets of national wealth. Each individual will perform his part in society with credit to himself and advantage to others in proportion to the amount of knowledge and skill which he brings to bear upon it, and these can only be acquired by study and research. Should this small treatise fall into the hands of any person engaged in agricultural pursuits, and so far excite his curiosity as to lead him to desire a further acquaintance with the subject, we would recommend him first to peruse a small work by Professor Johnston, entitled "Elements of Agricultural Chemistry and Geology." He will then be in a condition to peruse with profit the "Lectures" on the same subject by this excellent chemist. We would also strongly recommend Liebig's "Chemistry in its Application to Agriculture," a work in which the genius of this celebrated chemist is conspicuous. Boussingault's "Rural Economy" may also be read with advantage. Good English translations of both these works have been published.

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